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Author: A. S. Goldstein, G. B. Hawthorne, Jr.

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ABSTRACT

This report is Volume 4 of the Final Report on Mission Control Systems Effectiveness Analysis, NASA Contract T-53803-G. This volume describes the analysis performed on the MCC Display and Control System. Characteristics of the Display and Control System are discussed in terms of capacities and capabilities and then usage analyses based on actual GT-8 mission data are presented, followed by conclusions and recommendations.

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SECTION I

INTRODUCTION

The technical assessment and determination of limits of capabilities of the Display and Control System requires the establishment of objective standards and measurable criteria. In the absence of established measurement criteria there is no simple or formal method of determining when the MCC, or one of its major subsystems, in its present or planned configuration, will become a limiting factor in space flight control and operations. The display system has fulfilled its role successfully to date. The fact that it may, from time to time, require updating and redesign to fulfill future mission requirements that are not yet defined in adequate detail, is a source of concern. A formal and complete technical assessment of the display system current capabilities helps to provide a basis for determining equipment adequacy in regards to proposed redesign and configuration.

This volume of the report discusses the display system capacity and capability, in terms of various measures established during Task A1. During this task, display system block diagrams were prepared and submitted to NASA. This effort resulted in an insight into the physical nature of display system equipment. A subsequent set of usage analyses, concerned with operator actions and demands upon the display system, was done to acquire a complementary insight into the use of the display system. These usage analyses are discussed here in detail, and then a summary of conclusions is presented, based upon the usage analyses. This is followed by recommendations for continuing display and control system analysis which will aid NASA personnel in making design and procurement decisions.

SECTION II

GENERAL APPROACH

INTRODUCTION

The formal standards and criteria upon which to base qualitative and quantitative judgments of any of the MCC systems do not exist to any appreciable extent. One can state that the RTCC performed to some estimated value of design capability, the communications system experienced a certain number of outages in a specified mode of operation, or that the display system was characterized by a certain average time delay in fulfilling display requests. These measurements, by themselves, do not form very complete evaluations of equipment adequacy, nor do they reflect the overall system performance potential. Completeness in evaluating equipment design and subsequent performance is difficult because:

1. Modes of operation vary within and between flights.
2. Nominal flights and failures causing early and sudden mission termination do not test the facility and equipment to design limits.
3. Original design philosophies and documentation may not be reflected in actual implementation and operation of the facilities.
4. The operation of the equipment and facilities changes with use and experience.
5. Personnel have differing philosophies and capabilities with regards to operations and equipment usage.
6. Mutual dependencies between display and RTCC software are difficult to determine.
7. Equipment and personnel performance are difficult to predict in degraded or non-standard modes of operations.

Early in this study effort it was concluded that a gap existed in the documentation of the MCC design. No system design book, or books, were found that described and dealt with the MCC and its major systems on an adequate functional level. There were quite detailed and adequate specifications on equipment, and general descriptive documentation (as an example PHO-FAM 001) which were superficial in a systems engineering design sense. To both fulfill the task assignments, and help overcome the documentation gap it was decided to evolve a set of display system block diagrams. These would serve the following purposes:

1. Familiarize MITRE personnel with the display system and assure that MITRE had acquired a proper understanding of the system.
2. Provide NASA management with a coordinated set of block diagrams which present easily understood engineering-type information on the limits and capabilities of the display system.
3. Form a basis for the development by MSC of an MCC engineering system design book.
4. Serve as a launching platform into effectiveness and usage analyses of the display system.

In analyzing the capabilities of the display system it was decided that an analysis procedure was required that was not overly expensive and which could be used by NASA to aid in equipment selection during system augmentation. This analysis required the breaking down, or partitioning, of the MCC into subsystems which are further divided into parts to be analyzed. This suboptimization procedure requires that relationships and interfaces between systems and parts be carefully delineated. Fortunately, the display system is easily decoupled from the other MCC systems in the present configuration. The only interface area of concern was with the RTCC, and this interaction area was easily defined (except with respect to internal programming actions and delay times within the RTCC). Within the display system there were adequately defined interfaces between subsystems which were well documented in detailed specifications. This made the task of generating system block diagrams relatively simple, but tedious. It was felt that the best procedure was to trace data flow line-by-line (and sometimes bit-by-bit) in the form of open or closed loops through the display system, and then to present the pertinent information on block diagrams in an easy-to-read manner. This was accomplished under Task A1.

The next task consisted of performing usage analyses which would hopefully lead to an effectiveness analysis. This study was to be limited to evaluating equipment and format usage only, without much emphasis upon the operational aspects of how the display system is used by flight control personnel. However, it is difficult to completely decouple equipment performance and operational use and, in the usage analysis part of this study, some efforts were devoted to obtaining and analyzing data on how the display system was used by the GT-8 console operators. Usage data in the form of tables and graphs were developed, but judgments on the human and operational aspects based upon this data were considered beyond the defined scope of this initial four-month study effort.

DESCRIPTION OF ANALYSIS

The Display/Control (D/C) system has 5 subsystems, (CDCIS, TV, Console, Group Display, and Timing Subsystems) each having many elements.

This complex hardware configuration serves many functions, such as indication of events, control of computer program switching, status indication, and hardcopy generation; but most important (in the sense of need for analysis) is the display request/retrieval function. The man/machine interface involved here is an important one, particularly in the area of response time, i.e., the time between the initiation of a display request by a human operator and the delivery of the complete display by the system. Other aspects of importance are the loading on various parts of the system, the malfunctions which occur, the extent to which parts of the system are saturated (operating near their limits), the way in which console operators use their input devices, and the way in which they select various display formats. In this study, a limited look was taken at each of the above areas.

The analysis approach tends to be shaped by the partially random occurrence of flight controller actions; this together with other random factors, such as the times of occurrence of scheduled and unscheduled events or the number of real-time updates, imposes a varying load on the system which tends to require that any meaningful prediction of performance be in the form of a statistical or probabilistic statement (e.g., "the delay will not exceed 4 seconds for 90% of the display requests"). Such statements can be derived for demand/response systems, such as this one, either analytically from mathematical models (these must be based on experimental observations of the system), or experimentally from measurements taken on the system during operation; in cases where neither of these is feasible, it is sometimes possible to derive extremes of performance, in terms of "best case" and "worst case", by analyzing the system hardware and operational constraints.

The general approach taken in this analysis was a mixture of experimental measurement and best-case/worst-case approaches, with most emphasis on the former. Time did not permit the accumulation of sufficient detailed data to allow the construction of statistical models for predicting system performance under different conditions, hence the main result is to give a gross picture of the system's performance on one particular mission (GT-8), and to develop techniques and procedures that should ultimately aid NASA in making design and operational decisions concerning the display system. As a basis for the analysis, Task A1 was performed, i.e., each subsystem within the D/C system was broken down into component blocks of hardware, and each of these described at a very detailed level, in terms of its physical and functional characteristics.

From the basic and detailed data on the system elements, subsystem and system characteristics can be developed. At the system level of analysis, three factors stand out as important:

- The D/C system capacity and capability is shared by a number of console operators, on both a space and time basis (e.g., the D/TV Converter is shared on a space basis by allocation of its 28 physically separate channels, while the CIM is shared on a time basis by sequential scanning of its users).
- A single console operator uses, at most, only a small part of the D/C system at any given time.
- The system elements serving a given console operator in any given instance are utilized in sequential (series) chains, with the output of one element serving as the input of another. The complete set of elements forming such chains can be thought of as loops (open or closed) which either start, finish, or both start and finish, with the human operator.

Only a much more complete analysis than described here can adequately take into account the individual and random interactions implied by the first of the above factors. Instead, the performance and loading of various system elements in response to the aggregate demand of <u>all</u> console operators was statistically determined from data recorded during GT-8. The results are discussed under Display System Usage Data Analysis (Section IV).

As a consequence of the second factor above, it is reasonable to analyze that portion, or portions of the D/C system which are typically utilized by a single Console Operator in performing some monitoring or control function. Parts of the system which can serve all controllers simultaneously without any degradation of performance or which impose no appreciable response time constraints (such as the Group Display and Timing Subsystems), need not be included. Hence the CDCIS, Console, and TV subsystems remain as candidates for more detailed analysis.

As a consequence of the third factor above, it is desirable to analyze the performance of the various open and closed chains (or loops) of elements used for display retrieval and other functions. The analysis of a commonly - used closed loop (display-request loop) is given in Section III.

SECTION III

DISPLAY SYSTEM CAPACITY AND CAPABILITY

INTRODUCTION

Seven physical and functional characteristics of the system hardware were established as reasonable measures of capacity and capability; these were evaluated for various subsystem components as described below.

CHOICE OF MEASURES

The measures chosen for describing the D/C system (and their units, if any) are:

1. Capacity (various units - number of words, bits, positions, lines, channels, etc.)
2. Time Delay, Rate (bits, characters, positions, or frames per second, delays in seconds, etc.)
3. Reliability (usually in specified MTBF's, MTR's, redundancy, etc.)
4. Accuracy (% of full scale or nominal value, absolute accuracies in volts, cm., etc.)
5. Controllability (descriptive information about switchover capabilities and indicator and control panels).
6. Flexibility (description of possible alternative configurations, patchable connections, modes of use, etc.)
7. Expandability (number of additional units which can be accommodated, in absolute values or percentage of present capability, without extensive procurement and redesign of equipment).

Although there is some interdependence among these measures, and though not all of them can be described quantitatively, they do form a useful and reasonably complete set of descriptors for the system hardware. They arise naturally from a consideration of two modes in which humans interface with the hardware:

(1) During a mission, Flight Controllers and other console operators utilize the system hardware for monitoring and controlling the mission operations. In this mode, data and information-bearing signals are stored, transmitted, converted in form, processed, routed, and controlled; this immediately suggests system capacities, time delays and transmission rates,

equipment reliabilities and failures, absolute and relative accuracies, and ease or degree of human control, i.e., the first five measures, as being of interest.

(2) Between missions, engineers and technicians change and modify the system; this reconfiguration mode immediately suggests system flexibility and margin for expansion, i.e., the last two measures, as being of interest.

In addition to these measures, it is necessary to summarize the functional and physical relationships among the various hardware elements, i.e., the input/output relationships, data and control line connections, and transmission/processing control disciplines and logic. This suggests the use of annotated block diagrams; such diagrams also provide a convenient place for recording values of the various measures. Four such diagrams were produced during Task A1, and delivered. There were:

CHART I. CDCIS, Group Display, and TV Subsystems
CHART II. MITE (part of Timing Subsystem)
CHART III. RTA Complex (part of Timing Subsystem)
CHART IV. Console Subsystem

Each chart was produced as a basic block diagram plus a number of transparent, color - coded overlays. The block diagrams show such things as equipment names, groupings, and locations, as well as interconnections and descriptive information. The overlays give information relative to the various measures for the various components in the subsystems. These charts were originally produced for the purpose of self-education of the MITRE C/D team, but they have since become useful to NASA for other purposes.

APPLICATION OF CAPABILITY MEASURES

To illustrate the application of capability measures, a simplified analysis was made of a typical and much-used loop (display-request loop). This loop, which is closed (i.e., can be traced from a human operator through the system and back to the operator), was analyzed for response time, using data on time delays gathered under the Capacity and Capability Measures part of the effort.

All console operator requests for display formats originate with a manual request action by a console operator, using either an MSK or DRK, and terminate (completion of response) when the complete requested display appears on his console TV monitor screen. It is important, in such man/machine interactions, that the delay between request and response not exceed a certain value, generally taken to be in the order of 1 to 4 seconds. The actual delay in a given instance is random, depending on the amount of random, operator-imposed loading which the system is experiencing at that time. Hence the most complete picture of response delay is given by a statistical distribution of loop delay times. However, in the absence of a statistical model, it is still possible to calculate the best-case and worst-case delays, as follows.

As with all open and closed loops which originate or terminate with a console operator, the subject loop does not lie entirely within the Display/Control system. In particular, the display request loop passes through the RTCC system, where requests suffer a delay which is again random. This delay will be conservatively approximated by 2 milliseconds, assuming that the computer is unloaded and completely available to handle the incoming request.

Other sources of delay (assuming that the requested display is not already being generated), all lie within the D/C system and consist of the Computer Input Multiplexer (CIM), the D/TV Data Distributor (D/TV DD), the Converter Slide File Data Distributor (CSFDD), the D/TV Converter, and the Video Switching Matrix (VSM). It is assumed that the manual input device (MSK or DRK) and its associated encoder introduce no appreciable delay; likewise for the video and data transmission lines and the console television monitor. The display data flowing through the D/TV DD, CSF DD, and D/TV Converter is split into two parallel paths, both of which must be traversed before the complete display is generated. Hence the path having the largest delay (CSF DD and Converter Slide File, an element of the D/TV Converter) fixes the overall delay through this part of the loop. If the loop is traced backwards, beginning with the VSM, the various elements which fix the total delay are:

VSM - 100 msec. switching delay.
Converter Slide File - 3 seconds delay. (In the case where a slide file access is required).
CSF DD - 11 msec request transmission time.
RTCC - 2msec (approximation).
CIM - variable, depends on loading.

Since the above elements are in series around the loop, their delays add. The total delay is thus 3.113 seconds plus the CIM delay. The CIM delay is calculated below for the two extreme cases of CIM loading, i.e., for only one active CIM input scanning position (the display request being analyzed), and for all 1024 positions active (corresponding to maximum utilization of console/module scan positions, and assuming that simultaneous requests are being made at each position).

Minimum-Loading Case

In this case only the single subject display request is waiting to be scanned and transmitted by the CIM. The transmission of this one 36-bit word at the 2500 bit/sec rate introduces a delay of 36/2500 = 14.4 milliseconds (msec). The minimum scan delay occurs if the CIM scan reaches the active position at the same time as the request, in which case the scan delay is zero. The maximum scan delay occurs if the CIM scan <u>leaves</u> the active position just prior to the arrival of the request, in which case it must scan the remaining 1023 inactive positions before returning to the active one. Since the scan rate is 25,000 positions/second, the scan delay is $1024/25 \times 10^3 = 41$ msec. For a uniform (random) distribution of scan position with respect to active position at the time of the request, the mean scan delay is one-half the maximum, or 20.5 msec. Thus in the minimum-loading case the following CIM delays can result.

• Best Case (no scan delay):	14.4 msec
• Worst Case (Maximum scan delay):	55.5 msec
• Average Case (mean scan delay):	34.9 msec

Maximum-Loading Case

In this case all 1024 scan positions contain active requests, including the subject display request. The other requests are a mixture of inputs from various types of modules: MSK, DRK, FDK, PCK, ESW, SMEK, and ESO. All of these except the last three transmit a request with one computer word; the ESW may transmit 1, 2, or 3 words, while the SMEK and ESO always transmit 2 words. Most ESW transmissions are one word, however, and the number of SMEK and ESO modules is small compared to the total number of modules; hence it will be assumed that all modules transmit one word. The additional delay introduced by these 1023 other words is entirely transmission delay; the scan delays (maximum, minimum, and mean) remain the same as before. Hence in the maximum-loading case, the following CIM delays can result.

- Best Case (no scan delay, no extra transmission delay): 14.4 msec
- Worst Case (maximum scan and transmission delay):
  14.4 + 41 + (1023)(14.4) = 14,900 msec = 14.9 sec
- Average Case (mean scan and transmission delay):
  14.4 + 20.5 + (1023/2)(14.4) = 7,400.5 msec = 7.4 sec

Range of Delays

Based on the above minimum-loading best case and maximum-loading worst case, as well as the previously given delays in other parts of the system, the total delay experienced in obtaining the display would be as follows.

- Minimum delay - 3,113 msec + 14.4 msec = 3,127.4 msec = 3.1 sec.
- Maximum delay - 3,113 msec + 14,900 msec = 18,013 msec = 18.0 sec.

If the corresponding average cases are computed, the total delays become

- Minimum Average Delay -
  3,113 msec + 34.9 msec = 3,147.9 msec = 3.1 sec
- Maximum Average Delay -
  3,113 msec + 7,400 msec = 10,513 msec = 10.5 sec.

As can be seen, the minimum-loading best and average cases are essentially identical. Thus, a lower bound to the delay of a single request is 3.1 seconds, the bulk of which is accounted for by the Converter Slide File. Such a delay is within the bounds of acceptability, but the maximum-loading worst and average cases of 18.0 and 10.5 seconds are not. Exactly where the present configuration stands between these two extremes can be determined only by further analysis, but several observations may be made, as follows.

- All 1024 scan positions were not in use for GT-8, and probably will not be for some time (at least as far as console inputs are concerned). Hence the above maximum-loading delays are unduly pessimistic. Based on the approximately 100 scan positions in use for GT-8, the maximum average delay as calculated above turns out to be 3.9 seconds.
- Even if all 1024 positions were in use, it is extremely unlikely that they would all be active simultaneously. This would require that the flight controllers be simultaneously using eight input modules <u>at each</u> console. Not only is the average number of modules at each console considerably less than eight, but the modules are normally used one at a time. This factor immediately reduces the maximum delay to 4.9 seconds and the maximum average delay (for 1024 positions in use) to 4.1 seconds, a tolerable figure.
- Even with one active module per console, it is extremely unlikely that all consoles would make simultaneous requests, thus reducing the maximum delays still further.

In summary, it is likely that the present configuration is operating closer to the minimum values of delay than to the maximum. A more definitive statement of the present and predicted future situation is best made in statistical terms, e.g., a curve showing the probability (or percent time duration) of any particular delay, under prescribed conditions. Short of over-designing the D/C system to insure minimum delay under every conceivable condition, no matter how short the duration of the condition, the systems planner is left with this statistical approach as the best means for making the inevitable tradeoff between acceptable performance and cost.

The example above is intended both to give some indication of the present adequacy of the system for handling display requests, and to indicate the general approach that might be taken in a more complete analysis. The latter would require the development of equations expressing the CIM and RTCC delays in terms of the number of controllers making requests, the rate of arrival of the requests, and the loading of the RTCC.

SECTION IV

DISPLAY SYSTEM USAGE DATA ANALYSIS

INTRODUCTION

Upon completion of the study of the MCC Display System configuration, and the generation of system block diagrams, an analysis of Display System usage was initiated. This effort serves the purpose of providing an exploratory inquiry into approaches to usage analysis before undertaking any further extensive effort along these lines, and also helps to establish possible measures of effectiveness for the Display System. These usage studies do not include operational analyses, and therefore, any results stated must be interpreted in this light.

This display usage analysis task was structured by the limiting factors of (1) time available for the analysis, and (2) availability of usage data. Because of these limitations an attempt was made to select those study areas which were considered to be of most importance in the usage of the display system, and for which meaningful results could be obtained within the available time.

There has been no coordinated formal usage data analysis program at the MCC, and the short duration of this study precluded efforts to develop any extensive program of this sort. The philosophy adopted for the usage analysis was to make use of readily available data and computer routines, even though these were not ideally matched to the task in some cases.

The most valuable part of this analysis lies in its establishment of procedures and techniques that can be used for possible future analyses. This approach revealed areas where further data gathering would be advisable, and areas of study where the analysis of this data could lead to significant results and conclusions. These results and conclusions might then be profitably applied to, and affect redesign and acquisition of, both equipment and operational procedures. Correlations between mission characteristics and display system usage would also help to estimate and establish future design requirements and operational demands upon the display system.

The usage analysis was limited to the GT-8 mission which was selected because (1) it was of short duration and therefore manageable using manual tabulations, (2) contained a crisis period, and (3) was a complex mission involving two launches. The GT-8 mission was the latest mission for which data was available and was the mission for which personnel have accumulated the most experience with the MCC and its equipment. It was believed that this would help minimize the effect of operator learning on the usage data.

The main areas within the display system selected for usage analysis were:

1. The console subsystem (display request modules)

2. Computer display control interface subsystem (Digital/TV converter channel operation and computer input multiplexer)

3. Display format usage analysis

The timing subsystem, group display subsystem, the equipment portion of the television subsystem, and the hard copy facility were excluded from this usage analysis. It was felt that their relative importance and effects on future display system requirements and redesign would not be as great as for the other display areas selected for analysis.

The following specific usage analyses were made:

(1) <u>Digital-to-TV Channel Saturation</u> - This involved analyzing the history of occurrences of the red and amber lights (which indicate approaching channel saturation) during the entire GT-8 mission. This study shows the extent to which the D/TV channels operated at near-saturation, due to demand for display format requests, and relates mission times to these periods of near-saturation.

(2) <u>Life Systems Consoles</u> - This involved selecting a small functional group of consoles and studying, for this group, the usage of console modules and of dynamic display formats. This study, in addition to revealing the life systems group actions, serves as a model for analysis of all consoles and functional groups.

(3) Display Format Usage Analysis - This study provides relative usage statistics for all display formats provided for the GT-8 mission. The analysis considers the total number of MSK requests (by all consoles) for each of the dynamic displays, as well as the number of different displays requested during each of fifty 20-minute intervals covering the mission. Comparisons of display usage are made among the various functional groups of displays, and the effects of invalid requests and "clear monitor" requests are considered.

(4) Total Console Module Activity - This study reveals some of the characteristics of the usage of all console input modules during the entire GT-8 mission. The variation of keyboard activity with time is categorized by type and analyzed.

(5) Comparison of Manual Selection Keyboard and Display Request Keyboard - This study shows the relative usages of the MSK and DRK for several consoles containing both modules. It indicates operator preference, and in conjunction with the total console module activity analysis, reveals the possible consequences and effects on the display system of adding more modules of each type.

(6) Computer Input Multiplexer Loading - This study provides rough indicators of the loading and possible time delays for the CIM, and casts some light on the contemplated use of the CIM in the CCATS configuration.

(7) Digital-to-TV Channel Outage Statistics - This study was designed to reveal the D/TV channel reliability characteristics and their effects upon the statistical data of other analyses. Channel outages and their durations were recorded and summarized.

The major sources of data for all usage analyses were the mission log tapes and the knowledge of the display system developed from Tasks A1 and A2 of this four-month study. The computer program for delogging the mission tapes was the Philco Data Retrieval and Interpretation Program (DRIP). This delog program (apparently developed for other reasons for NASA, and the only useful program found to be readily available) produced computer printouts from which data were manually reduced and tabulated into the desired forms. The following paragraphs present the purpose, procedures, results, and conclusions of the usage studies.

DIGITAL/TV CONVERTER CHANNEL SATURATION ANALYSIS (RED-AMBER CONDITIONS)

Purpose

A major area of concern within the Display System is whether the present number of D/TV converter channels is sufficient to support future missions. This usage analysis reveals, for GT-8, the time history and statistics of the red and amber warning lights which are indications of saturation, or near-saturation conditions in these channels. The amber light indicates 24 or 25 converter channels, and the red light indicates 26 to 28 converter channels, out of a total of 28 channels, are in use and hence not available for new display requests. The purpose here was to analyze the occurrences and durations of three conditions: red condition (0 to 2 channels available), amber condition (3 to 4 channels available), and red-or-amber condition (0 to 4 channels available).

Procedure

The data indicating red and amber conditions for GT-8 was obtained from the mission log tapes by using the Philco Data Retrieval and Interpretation Program (DRIP) to delog the mission tapes. The print-out produced by DRIP contained the GMT times that the red and amber lights changed from ON to OFF and vice versa. This data was collated manually and arranged to present the total seconds the lights were on, the durations of the ON state for each occurrence, and the number of ON occurrences during 50 twenty-minute time intervals starting at 00/12/20'00 GMT. This 1000-minute duration spans pre-mission to post-mission time for GT-8, which was about 900 minutes long. Twenty-minute intervals were selected as being short enough for useful results and yet allowing the analysis to be done in the time available. One could investigate channel usage during shorter time intervals for specified mission phases, at the expense of extra data reduction time.

Results

The data was used to generate curves which graphically illustrate D/TV converter channel usage characteristics.

Figure 1 indicates the total seconds that either red or amber lights (sum of times) were ON during each 20 minute interval. It is interesting to note that the red and amber lights were ON during an entire twenty-minute interval only once (interval 22). Also of interest is the fact that during both Agena launch and Gemini launch time phases, amber and red conditions were not as great as they were during the orbit period (which begins at about interval 15 and ends at about interval 35). This may have been due to an operational procedure which requires personnel to have their display requests initiated and unchanged from three minutes prior to launch until orbit phase is achieved. The absence of any red or amber conditions during intervals 30 and 31 is indicative of a quiescent period. This is possibly due to an operational procedure causing clearing of the channels, or the ending of the first shift of controllers. The rise in red and amber conditions after those intervals might be the beginning of the second shift. There was no indication that this rise was due to the crisis which led to an abort (this did not occur until interval 34). The red-or-amber condition falls off rapidly after the crisis was detected, probably indicating that updated display data was not available, and that there was no need for many controllers to call up display formats during re-entry.

Another curve (Figure 2) indicates the percentage for each time interval of the fifty 20-minute time intervals (100 percent is equivalent to 1200 seconds), that the red light was on, the amber light was on, and either the red or the amber light was on. This graph indicates that red ON condition occurred during interval 23 about 50 percent of the time. The sudden drop at interval 24 might have been due to an operational procedure or a request to all controllers to clear channels and use them only if necessary. The average duration of the red condition was considerably lower for the remainder of the mission (approximately 24 percent for intervals 13 to 30).

The amber light is on for slightly more than 40 percent of the time between intervals 15 and 28, and reached a maximum level of 57 percent at interval 21.

Figure 3 is a histogram of red, and of red-or-amber durations which shows the number of occurrences of these conditions for specified time durations of each occurrence. As an example, the number of red conditions which lasted from 1 to 10 seconds was about 50, and the number of amber conditions lasting from

1 to 10 seconds was about 85. There were no red conditions which had a time duration of 60 to 70 seconds, and there were about 19 occurrences of amber which lasted for 60 to 70 seconds. The histogram indicates that, for most of the mission, the durations of red-or-amber condition were less than 40 seconds (68.3 percent of all occurrences), and very few durations were greater than 120 seconds (4.4 percent). This Figure also indicates the cumulative distribution of red-or-amber condition, showing percent of occurrences (based on a total of 440 occurrences) as well as number of occurrences.

Table 1 contains a tabulation of the number of occurrences of the red and amber lights by 20-minute time periods. The existence of intervals having high percentages of red or amber time is associated with the occurrence of comparatively long durations (greater than one minute) rather than with the number of times the lights went on during that interval (as indicated during interval 22). It should be noted that red condition does not necessarily mean all D/TV converter channels are in use.

Conclusions

Although no single value or number can be stated as to the amount of D/TV converter channel saturation experienced, it appears from the data that for most of the GT-8 mission, the capacity of this part of the display system was adequate (assuming a limited amount of red condition is considered acceptable).

It would be of further interest to observe the status of red and amber conditions during a mission with a longer orbital period containing other events such as space walks and several flight controller shift changes. These conditions would be more indicative of what to expect for future missions and would help establish any correlations between display usage for a mission and converter channel saturation.

Before statements are made as to the adequacy of 28 D/TV converter channels for a particular mission, it would be advisable to perform this analysis (and other analyses discussed in subsequent sections) for missions other than GT-8. Thus trends could be detected and correlations made between channel saturation and the factors of mission complexity, mission duration, and number of display formats available. NASA could then make a better judgment as to whether the present number of D/TV converter channels in the display system is adequate for future

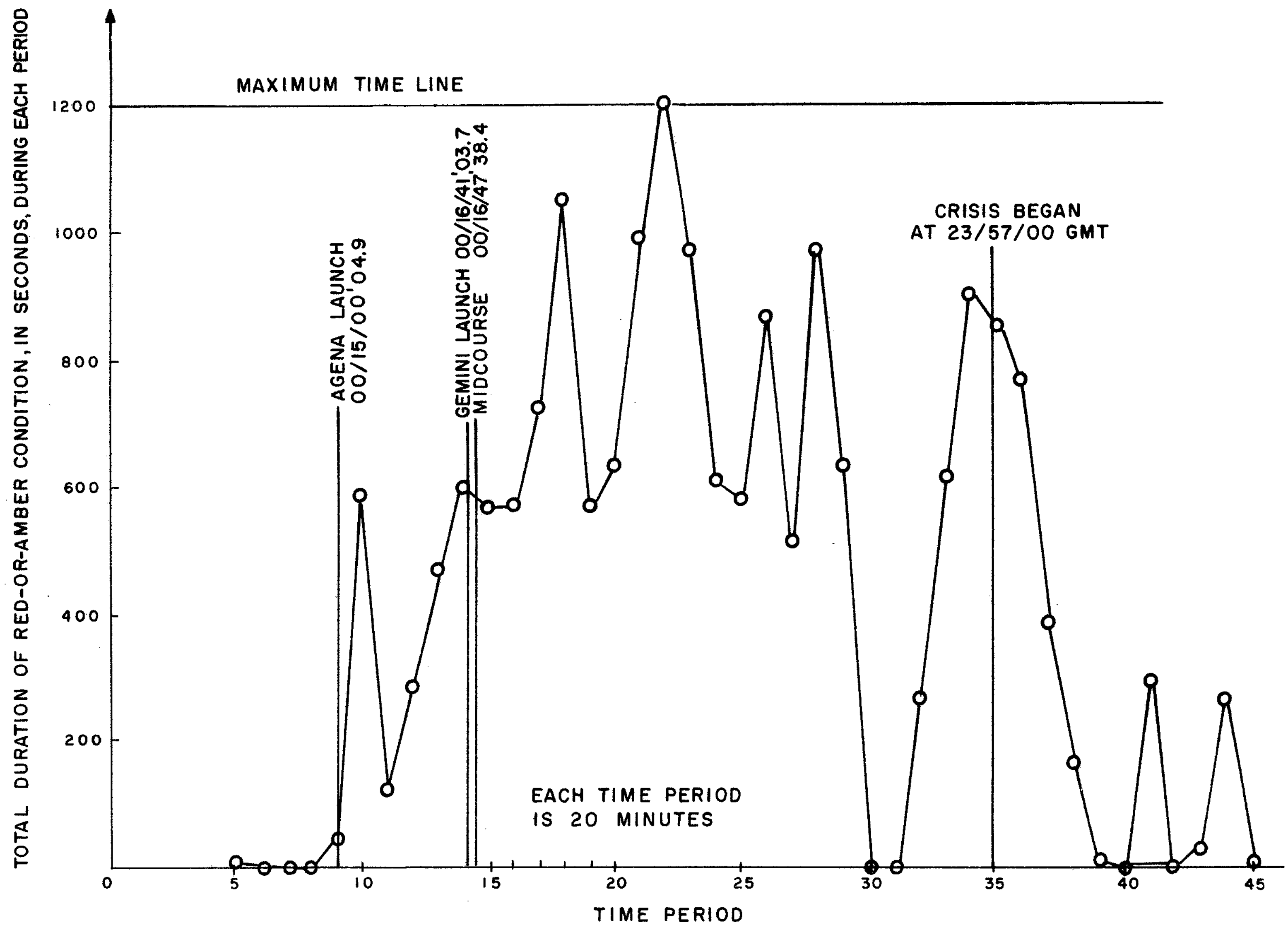

Figure 1. Red Or Amber Condition For GT-8 During 20-Minute Intervals

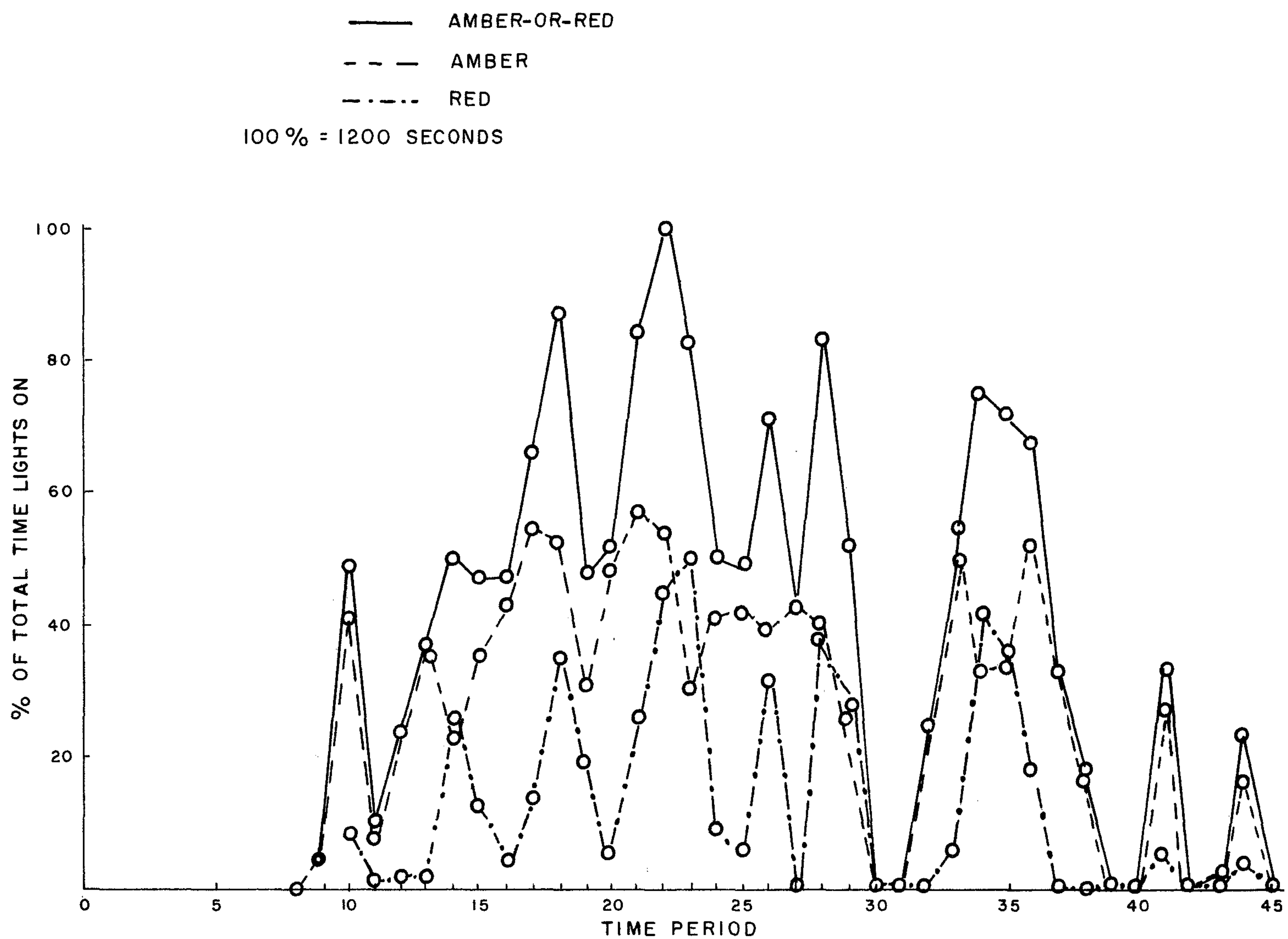

Figure 2. Percentage Of Total Time Red, Amber And Both Lights Were On

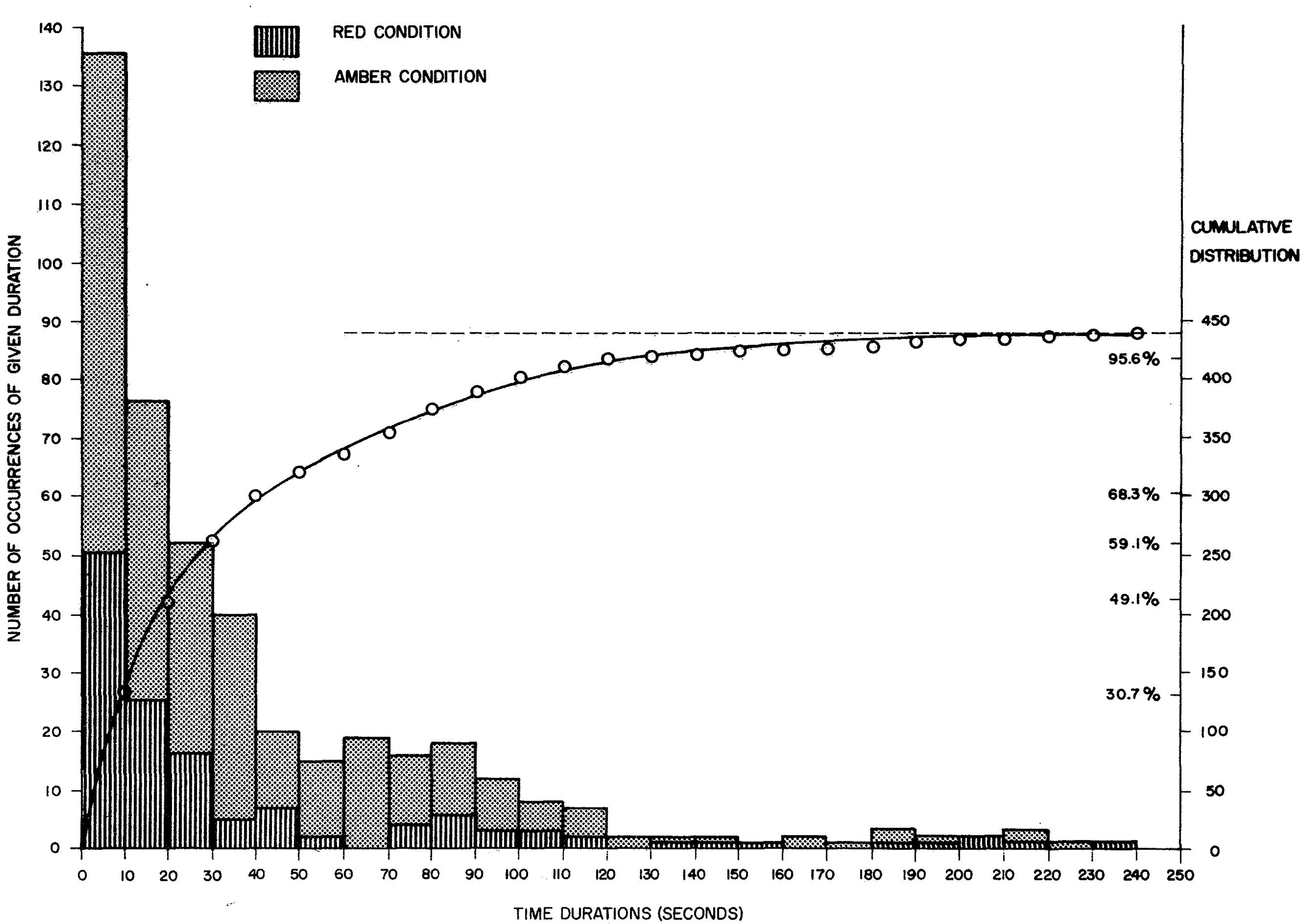

Figure 3. Histograms Of Red And Of Red/Amber Durations And
Cumulative Distribution Of Red/Amber (10-Seconds Histogram Levels)

Table 1
Occurrences of Lights by Time Interval

	AMBER CONDITION			RED CONDITION		
Time Period	Number of Occurrences	Number of Durations of ON Condition Greater than 1 Minute	Number of Durations of ON Condition Greater than 2 Minutes	Number of Occurrences	Number of Durations of ON Condition Greater than 1 Minute	Number of Durations of ON Condition Greater than 2 Minutes
1-4	0	0	0	0	0	0
5	1	0	0	0	0	0
6-8	0	0	0	0	0	0
9	2	0	0	0	0	0
10	14	4	0	8	0	0
11	1	1	0	1	0	0
12	8	2	0	2	0	0
13	11	4	0	2	0	0
14	12	1	0	10	1	0
15	14	2	0	7	1	0
16	13	4	1	4	0	0
17	15	5	0	3	1	1
18	16	5	0	8	3	1
19	16	1	1	4	1	1
20	7	3	2	2	0	0
21	19	4	0	10	1	0
22	7	3	1	5	4	2
23	17	3	0	11	3	2
24	11	2	1	3	1	0
25	17	3	0	5	0	0
26	18	3	0	8	2	1
27	15	1	1	1	0	0
28	18	5	0	10	4	0
29	7	3	0	5	2	1
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	7	1	0	0	0	0
33	10	4	1	5	0	0
34	8	1	1	7	4	1
35	5	2	2	3	1	1
36	13	5	0	5	1	0
37	7	4	0	0	0	0
38	5	1	0	0	0	0
39	2	0	0	0	0	0
40	0	0	0	0	0	0
41	2	1	1	1	1	0
42	0	0	0	0	0	0
43	1	0	0	0	0	0
44	3	1	1	2	0	0

missions or needs expansion, and if the latter, by what amount. However, based on just the GT-8 data, no clear case can be made for more channels.

This type of analysis could be fairly easily performed for all missions by developing computer programs (perhaps by revising or modifying DRIP) that delog, format, and analyze the data from the log tapes in one operation.

LIFE SYSTEMS CONSOLES DISPLAY FORMAT USAGE ANALYSIS

Purpose

The purpose of this study was to investigate, via analysis of display format request data, the nature of the activities of a functional group of consoles. It included the determination of which functional groups of displays were utilized by the chosen functional group of consoles. The Life Systems Console group was selected for this sample analysis mainly because of the tractable size of the data sample. The Life Systems group consists of three consoles (Life Systems Officer in the MOCR, and the two Life Systems consoles in a staff support room), all of which were characterized by a relatively low level of display request activity for the GT-8 mission.

The maintenance and operations group of consoles had originally been selected for analysis. However, it was discovered, before requesting delog data, that these consoles were highly active in an off-line monitoring and checking function. The maintenance and operations consoles are characterized by the continuous sequential and rapid selection of displays, apparently in order to fulfill their function of monitoring the condition of displays and equipment in the system. This type of activity would not properly serve the purpose of this study, which included the comparison of display-retrieval activities among several consoles engaged in direct mission support activity.

By studying and analyzing all functional groups of consoles, one should obtain a composite picture of the display activity in the MCC. This could reveal relationships between and within functional groups as to their common needs for certain display data as well as variations in their uses of equipment. Such a complete study could reveal display format preferences, needs for closer coordination between functional groups, and possible enhancement of both display design and operational procedures.

Procedure

Individual computer printouts for each of the three Life Systems consoles were obtained from DRIP. This data was manually reduced to show console module actions, time histories of display requests, and "up" time of displays. These data were divided into TV channel requests and display format requests.

Results

The display-retrieval actions for MSK modules were divided into display format requests and TV channel requests, and these were analyzed separately. Table 2 indicates the TV channel number requested, the display name, the number of times the display was called, the duration of the display on the TV monitor at each call-up, and the total time the display remained on the console TV monitor during the time interval between 00/12/12'00 to 01/04/00'00. It should be noted that the duration of the display on the television monitors, as shown in the total up-time column, does not necessarily correspond to the actual time the operator viewed or used the display. The total up times do represent maximum possible viewing time of the display by an operator or operators. Those channels that were called up three or less times, and with no single duration of up-time greater than 10 seconds, are grouped at the end of each list for each console. These actions are probably due to mistakes in dialing the proper MSK number or to searching on the part of the operator, and they have negligible effect on the statistics of the analysis data.

Table 2 indicates that the Life Systems Officer devoted most of his TV channel viewing time to:

(1) the three remote television cameras (for 267 minutes)

(2) the two life systems opaque televisors (for over 205 minutes)

(3) four digital/TV converter channels with undetermined display formats (for 566 minutes)

TABLE 2

TV CHANNEL REQUEST ANALYSIS (Life Systems Consoles)

Life Systems Officer				
TV Chan.	Display	No. of Calls	Total Up Time	Durations of Calls (Min: Sec.)
09	D/TV *	1	93:13	(93:13)
12	(Unknown	8	382:14	(93:10) (31:54) (0:32) (32:31) (18:37) (0:21) (58:52) (144:17)
23	Display	3	21:49	(0:18) (21:16) (0:15)
28	Format)	2	68:16	(57:36) (10:40)
47	Remote 1 TV	8	113:10	(105:29) (0:06) (0:17) (7:06) (0:04) (0:02) (0:03) (0:03)
48	Remote 2 TV	6	11:03	(0:07) (5:34) (5:01) (0:14) (0:04) (0:03)
51	Remote 3 TV	10	142:38	(1:11) (14:21) (11:53) (0:08) (0:38) (8:27) (20:53) (35:42) (49:23) (0:02)
58	L.S. Opaque TV # 1	6	186:50+	(51:18) (49:48) (25:43) (49:16) (10:45) (last entry)
54	L.S. Opaque TV # 2	3	18:44	(0:03) (0:18) (18:23)
49	Recov. Opaque TV	4	0:37	(0:03) (0:04) (0:15) (0:15)
52	Recov. Grp. Displ. Rear	2	0:15	(0:11) (0:04)
68	Meteor. Opaque TV	1	Undet.	Last Entry
57**	Time Summ. Conv.	1		(0:04)
50**	Recov. Grp. Disp. Front	3		(0:04) (0:03) (0:06)
46**	RSF 10	1		(0:02)
53**	Spare	2		(0:01) (0:02)

TABLE 2

TV CHANNEL REQUEST ANALYSIS (Life Systems Consoles Cont'd)

Life Systems Console No. 1				
TV Chan.	Display	No. of Calls	Total Up Time	Duration of Calls (Min: Sec.)
47	Remote 1 TV	12	109:50+	(0:05) (9:38) (10:45) (4:16) (4:48) (0:02) (0:03) (0:04) (0:03) (45:36) (34:30) (last entry)
48	Remote 2 TV	4	0:16	(0:03) (0:09) (0:02) (0:02)
51	Remote 3 TV	8	152:40	(20:53) (16.57) (0:17) (13:18) (8:28) (92:42) (0:04) (0:01)
49	Recov. Opaque TV	5	166:03+	(0:05) (0:41) (77:43) (62:54) (24:40) (last entry)
52	Recov. Grp. Displ. Rear	6	186:00	(0:17) (24:55) (36:07) (35:15) (0:02) (89:23)
57	Time Summ. Conv.	4	299:43	(4:19) (0:09) (295:15) (0:01)
68	Meteor. Opaque TV	2	42:57	(5:08) (37:39)
64	Veh. Sys 1 Opaque TV	3	5:56	(5:53) (0:02) (0:01)
65	Veh. Sys 2 Opaque TV	3		(0:11) (0:04) (0:01)
50	Recov. Grp. Displ. Front	3	0:36	(0:03) (0:09) (0:24)
58	L.S. Opaque TV # 1	3	1:38	(0:17) (1:20) (0:01)
54**	L.S. Opaque TV # 2	1		(0:01)
46**	RSF 10	1		(0:06)
53**		2		(0:03) (0:01)
55**		1		(0:02)
56**		1		(0:01)
59**		1		(0:02)
61**		1		(0:04)
62**		1		(0:02)
63**		2		(0:05) (0:01)
66		2		(0:16) (0:01)
67**		1		(0:02)

TABLE 2

TV CHANNEL REQUEST ANALYSIS (Life Systems Consoles Cont'd)

Life Systems Console No. 2				
TV Chan.	Display	No. of Calls	Total Up Time	Durations of Calls (Min: Sec.)
01**		1	34:46	(0:02)
02		2		(0:01) (34:45)
03-08**		for < 0:06		
12	D/TV*	5	89:16	(7:21) (57:33) (5:00) (19:03) (0:19)
20	(Unknown display format)	1	3:22	(3:22)
21**		1	0:14	(0:14)
47	Remote 1 TV	7	40:03+	(0:07) (0:04) (1:33) (11:33) (26.27) (0:02) (0:17) (last entry)
48	Remote 2 TV	6	3:35	(0:01) (0:08) (0:02) (0:07) (0:01) (3:16)
51	Remote 3 TV	9	177:25	(11:06) (55:09) (0:17) (6:20) (9:44) (94:39) (0:02) (0:04) (0:04)
49	Recov. Opaque TV	4	61:00+	(0:02) (0:04) (1:42) (59:12) (last entry)
64	Veh. Sys 1 Opaque	2	2:54	(2:52) (0:02)
65	Veh. Sys 2 Opaque	2	0:32	(0:30) (0:02)
68	Meteor. Opaque TV	4	11:43	(0:05) (0:11) (11:23) (0:04)
40**		1		
41**		1		
45**		1		
46**		1		
50**		1		
52-36**		1		
66**		1		
67**		1		
69**		1		

* The display formats on the D/TV channels are unknown since there is no readily available record of what format is on what D/TV channel as a function of time.

** These channels were called up three or less times with no single call-up duration greater than 10 seconds.

From Table 3, Display Format Analysis, the Life Systems Officer requested only two display formats. One was the TV Guide and the other display format, briefly viewed, was an RTCC display. The Life Systems Officer never requested a Life Systems display format although he may have viewed some of these formats on the D/TV channels. Apparently channel 12 of the D/TV converter channels contained a display (or displays) of great interest to this controller.

The Life Systems Console No. 1 operator selected, via channel requests, the remote television cameras 1 and 3, recovery opaque televisor, recovery room rear group display, time summary converter display, and the meteorology opaque televisor for most of the time. It should be reiterated that the total up-time of each display does not necessarily represent the actual time the operator viewed the display. From the display format analysis (Table 3) this operator also held display format No. 0803 (Gemini Physio Meters) on his monitor for about 223 minutes, format No. 0801 (Physio Sum Hist) for about 10 minutes, and briefly looked at format No. 0802. These three display formats were the only life systems display formats requested by any of the Life Systems group.

The Life Systems Console No. 2 operator had either the remote television cameras 1 and 3, recovery opaque televisor, or D/TV converter channel 12 (the same converter channel preferred by the Life Systems Officer) available for viewing most of the mission. From Table 3 one can observe that the Console No. 2 operator requested many display formats via the MSK display request mode, preferring the following display formats:

1) 0628 EECOM Display (ECS-COOL TAB) - 313 min.

2) 0629 EECOM Display (ECS-COOL HIST) - 71 min.

3) 0721 EECOM Display (FC-ELS SUPPLY TAB) - 350 min.

4) 0726 EECOM Display (ECS+FC T/PS)-- 360 min.

A life systems display format was never called up by the Life Systems Console No 2 operator.

Figure 4 summarizes the total "up" time and number of times each display format was called up through the MSK display format request mode. It indicates that of all dynamic

Table 3
Display Format Analysis (Life Systems Consoles)

	Functional Area	Format No. (MSK)	No. of Calls	Total Uptime (Min.)	Durations of Calls (Min.)
Life Systems Console No. 1	Life Sys.	0801	2	10.10	(1:39) (8:27)
	"	0802	1	0.37	(0:22)
	"	0803	7	222.93	(113:19) (4:34) (18:49) (18:43) (18:35) (0:03) (48:53)
Life Systems Officer	RTCC	1583	5	3.47	(0:35) (0:47) (0:14) (0:39) (1:13)
	TV Guide	1570	7	18.7	(4:49) (11:59) (0:11) (1:19) (0:44) (0:16) (0:22)
Life Systems Console No. 2	Comm	0905	11	341.98	(75:18) (74:15) (5:10) (0:18) (2:30) (9:09) (23:00) (1:01) (88:16) (10:17) (52:45)
	EECOM	0626	1	5.97	(5:58)
		0628	9	313.17	(1:41) (7:10) (45:59) (71:31) (90:14) (22:51) (43:95) (9:09) (21:26)
		0629	1	70.45	(70:27)
		0630	1	0.18	(0:11)
		0700	1	0.07	(0:04)
		0701	1	0.07	(0:04)
		0702	1	0.15	(0:09)
		0711	1	0.17	(0:04)
		0712	1	0.10	(0:06)
		0713	1	0.07	(0:04)
		0716	1	0.07	(0:04)
		0717	1	0.73	(0:44)
		0721	6	350.15	(18:30) (6:48) (0:17) (0:25) (93:24) (230:45)
		0722	1	40.67	(40:18) (0:22)
		0723	3	2.12	(0:16) (1:32) (0:19)
		0724	1	0.03	(0:02)
		0725	1	0.03	(0:02)
		0726	6	359.36	(157:02) (25:48) (0:45) (137:00) (38:51) (0:10)
		0727	1	0.12	(0:07)
		0728	1	0.07	(0:04)
		0729	1	0.05	(0:03)

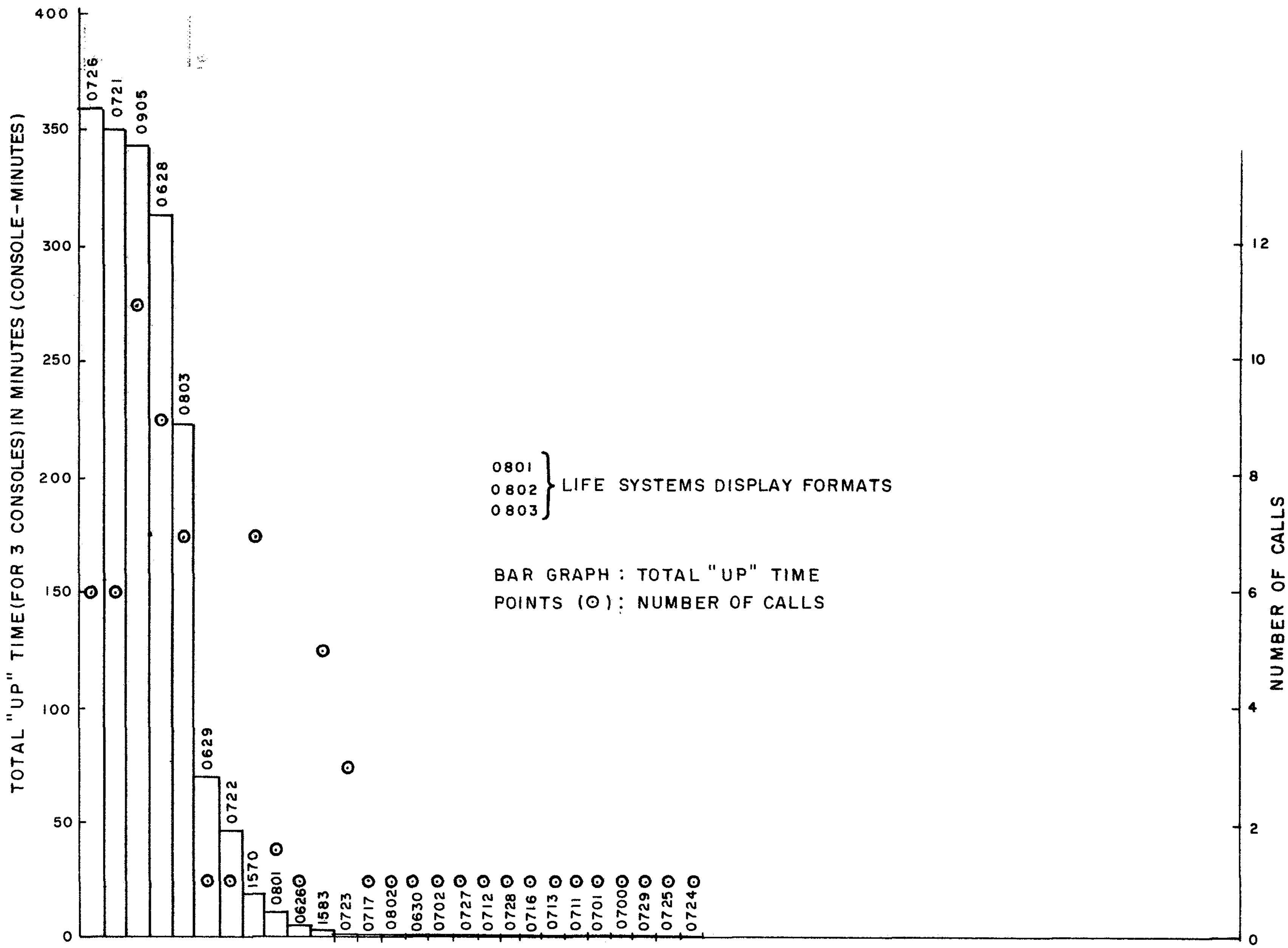

Figure 4. Display Format "Up" Times For Life Systems Consoles

display formats requested, only a few (formats 0726, 0721, 0905, 0628, 0803, 0629, and 0729) were "up" for more than 20 minutes during the entire mission. As one might expect, there is a definite correlation between the sum of "up" times and the number of times a display format was called. Of the eight available life systems dynamic displays, three were requested (0801) 0802, and 0803) by Life Systems Console No. 1 and none were requested by the other two consoles in this functional group.

Conclusions

A more complete analysis, considering the purpose and content of each format and including discussions with the Life Systems personnel, would have to be made before reaching any firm conclusions about the importance, use, and necessity of the various Life Systems display formats. There could be several reasons for lack of use of a dynamic display during the mission, such as:

(1) the unscheduled termination of GT-8 precluding the performance of experiements

(2) poor display format

(3) purpose of a display (which could have been connected with special events that did not occur)

(4) low probability of need for the data on the display

The amount of use of a display is not the only criteria for recommending inclusion or omission of that display. However, this study indicates which displays should be investigated in more detail in order to determine if they are candidates for removal, should it become necessary to reduce the number of display formats. This may happen, since as the number of dynamic displays increase, both computer and display systems become taxed. This may be considered less preferable, of course, than the alternative of procuring additional display and computer system capacity.

DISPLAY FORMAT ANALYSIS

Purpose

One objective of this analysis was to determine which dynamic display formats were called, when, and how often. Since this is a preliminary analysis, another objective is to develop procedures to serve as examples of how such data is acquired and analyzed. This effort also reveals the kinds of results and possible conclusions that may be achieved in a more comprehensive analysis.

Procedure

The analysis was accomplished in several steps:

- A DRIP delog printout showing console input actions during 50 contiguous and equal time intervals covering the entire mission was examined, and MSK display format requests were noted. (DRK display requests were not included in this analysis because of manpower constraints).

- Information as to MSK format number called, calling console, and time interval was transferred to a 14,700 - element matrix, described below.

- Summary data was abstracted from the matrix and entered on summary data sheets; these were used to plot curves describing the use of display formats by console operators during GT-8.

- Conclusions of the types that might be drawn in a more complete analysis were made on format usage, display system loading, and relative demand for various displays.

Matrix of Format Requests

A section of the format-request matrix is shown in Table 4. The 50 rows of the matrix represent the 50 twenty-minute time intervals.

Table 4

Part of Format-Request Matrix

Values of i	Values of j (and Display Format Numbers) 1 (0004)	2 (0005)	3 (0006)	4 (0007)	5 (0008)	294 (1600)
1	54 / 1	/ 0	/ 0	/ 0	/ 0	
27	/ 0	/ 0	52,37,54 / 3	52,52,54, 53 / 4	/ 0	
28	/ 0	/ 0	54,56,52 / 3	37,54,56, 54 / 4	/ 0	
29	/ 0	/ 0	53,56 / 2	52,53,53, 53,53,53, 56 / 7	/ 0	
50						

The i^{th} row ($i = 1,2,3,---,50$) contains data only from the i^{th} time interval. The 294 columns of the matrix represent the 294 dynamically updated display formats stored in the computer during the mission. The j^{th} column ($j = 1,2,3,----,294$) contains only data concerning the j^{th} format. Note that j is only an index number, and is not the format number, although the latter was entered at the top of each column.

The actual entries made in the cells of the matrix were calling-console numbers. Hence, the numbers 52, 53, and 54 appearing in the cell which is in the 4^{th} column and 27^{th} row indicate that consoles 52, 53, and 54 each requested the 4^{th} format (format 0007) during the 27^{th} time interval. Actually, the number "52" appears twice; this indicates two separate calls for the format by console 52, making a subtotal of four calls during this interval. This subtotal number of calls was also entered in the matrix cell; thus the number "4" appears in the lower right corner of the cell for $i = 27$, $j = 4$.

Time did not permit the use of the console numbers in the analysis, hence only the subtotals were used. Each subtotal represents the number of calls for a given format during a given time interval, regardless of whether the calls were all from the same console or from many consoles. It may be of some interest to note that the matrix, in its physical form, was made up of 111 ruled sheets of paper, each 16 by 22 inches, and covered a wall area of 272 square feet.

Results

Two basic types of summary data were obtained from the matrix subtotals; these are sets of numbers denoted by N_i (the number of different formats requested during the i^{th} interval) and S_j (the number of requests for the j^{th} format during all fifty time intervals). The fifty values of N_i, as tabulated in Table 5, were obtained by horizontally scanning each of the fifty rows of the matrix (Table 4) and counting the number of cells in the row for which the subtotals were greater than zero. A non-zero subtotal in a given cell indicates that the format in whose column the cell falls was called at least once. Hence the number of such non-zero subtotals is the number of different formats requested (at least once) during the time interval for that row. For example, the third row contains 14 subtotals which are not zero, hence 14 different formats were requested during the third time interval, and

Table 5

VALUES OF N_i

i	N_i	i	N_i	i	N_i	i	N_i
1	30	14	42	27	42	40	28
2	16	15	38	28	48	41	29
3	14	16	32	29	50	42	23
4	18	17	34	30	29	43	32
5	25	18	39	31	29	44	36
6	18	19	34	32	40	45	17
7	8	20	19	33	31	46	21
8	19	21	41	34	28	47	20
9	22	22	32	35	19	48	21
10	49	23	39	36	28	49	14
11	40	24	48	37	24	50	15
12	39	25	41	38	35		
13	37	26	42	39	44		

Notes: i = Time Interval Number (20 minute intervals)

N_i = Number of Different Formats Requested in Time Interval i.

$N_3 = 14$. The actual display formats requested were 0480, 0481, 0482, 0483, 0484, 0485, 0712, 1090, 1110, 1222, 1223, 1240, 1301, and 1570. It should be noted that some of these formats were called more than once by the same console, and by more than one console, hence the number of calls for these 14 formats during this interval is considerably larger than 14 and this should be borne in mind when considering the numbers and values quoted below for N_i data. If time had permitted, it would have been preferred to modify the simple definition of N_i in several ways.

The 294 values of S_j shown in Table 6, were obtained by adding the subtotals in each of the 294 columns of Table 4. Thus S_j is the total number of times the $j^{\underline{th}}$ format was requested during the entire mission, (via MSK display format requests only). For example, the sum of the subtotals in the $4^{\underline{th}}$ column of the matrix is 166, hence $S_4 = 166$, indicating this many MSK calls for the 4th format (format 0007) during GT-8. The sum of the S_j is the total number of MSK display format requests (all formats, all consoles, entire mission); this grand total number of MSK calls in 3,823. If DRK calls had been included, the number would have been about 5400. Table 6 lists the values of S_j versus j and the corresponding format number; these entries are grouped according to the fifteen functional categories of display formats. In a complete analysis DRK requests would be included and thus S_j would be a true value of total display format requests for the entire mission.

<u>Analysis of N_i Data</u>

A time history of N_i from Table 5, is plotted in Figure 5, showing the number of different display formats called during each twenty-minute interval. Although N_i is not directly proportional to the number of calls for displays, it is a rough indicator of console activity; as such, it indicates low activity near the start and end of the mission, with at least two significant peaks in between. N_i is probably more significant, however, as an indicator of the number of D/TV channels in use, since, at a given time, the number of different displays being used is equal to the number of channels in use. Again, N_i in its present form does not give very detailed information as to channel usage, for several reasons. First, it is computed over a twenty-minute interval, whereas the number of channels being used may change many times during twenty minutes. Since the requests for displays are spread out over the interval, and do not occur simultaneously, a value for N_i of more than 28 does not necessarily indicate channel saturation. Furthermore, some of these requests will be serviced by means of a TV channel latchup, in the cases where the requested display is already being generated in a channel. On the other hand, displays requested in previous intervals may still be occupying channels during the interval of interest; this tends to make the number of channels in use be larger than the number of different displays requested in the interval of interest. N_i becomes a more valuable indicator as the time interval considered becomes smaller. Finally, not all display requests are assigned a channel (under completely saturated conditions); tending to balance this factor is the fact that DRK - requested formats (not included in the analysis) result in more channel assignments than would be estimated from N_i alone. On balance, it appears that N_i may serve as a good indicator (provided one includes DRK requests, uses a smaller time interval, and includes channel usage history). From Figure 5 the minimum number of different formats called during any interval is 8, the maximum number is 50, and the average number is about 30. The distribution (histogram) for N_i is shown in Figure 6. For the histogram increment chosen, the curve shows that N_i lay between 14 and 43 for 88% of the time; this is obtained by adding the percent of time intervals (given on one of the vertical scales) for the five increments lying between 14 and 43.

Analysis of S_j Data

S_j, the number of calls (via MSK display request mode only) for a given format during the mission, varied over a wide range. A few formats had very large values of S_j, indicating frequent use, while a large number of formats had small values of S_j, indicating infrequent use. Approximately 31% of the formats were not called (mostly the display formats assigned to the network controller), even once, during the mission ($S_j = 0$). Table 6 reveals which formats had any given number of calls; it shows, for example, that format 0308 had no calls ($S_{39} = 0$), format 0461 had 17 calls ($S_{50} = 17$), and format 0017 had 356 calls ($S_9 = 356$). Format 1570, the "TV Guide", had 55 calls. It should be noted that S_j indicates only how often a display was called, not how long it remained on a monitor; furthermore, a format called only once may be on many monitors (via TV channel requests). Intuitively, it would seem that displays viewed for long periods (large "up" time) would have a small number of calls, and vice versa. However, this was not borne out by the analysis of the Life Systems consoles described earlier.

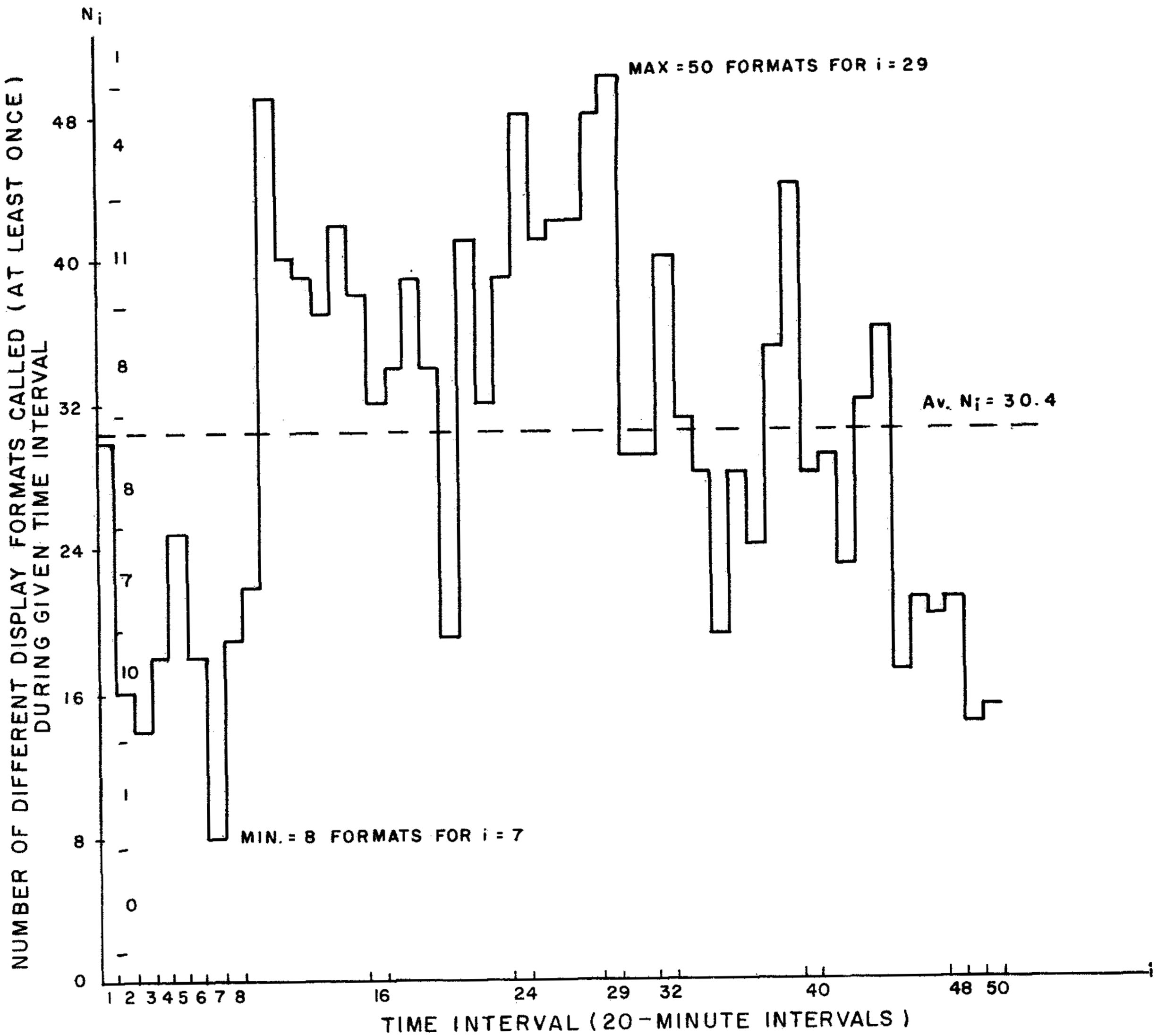

Figure 5. Number Of Different Display Formats Called Via MSK's Versus Time Interval (For All Consoles, Repeated Calls From Same Console Counted As Separate Calls)

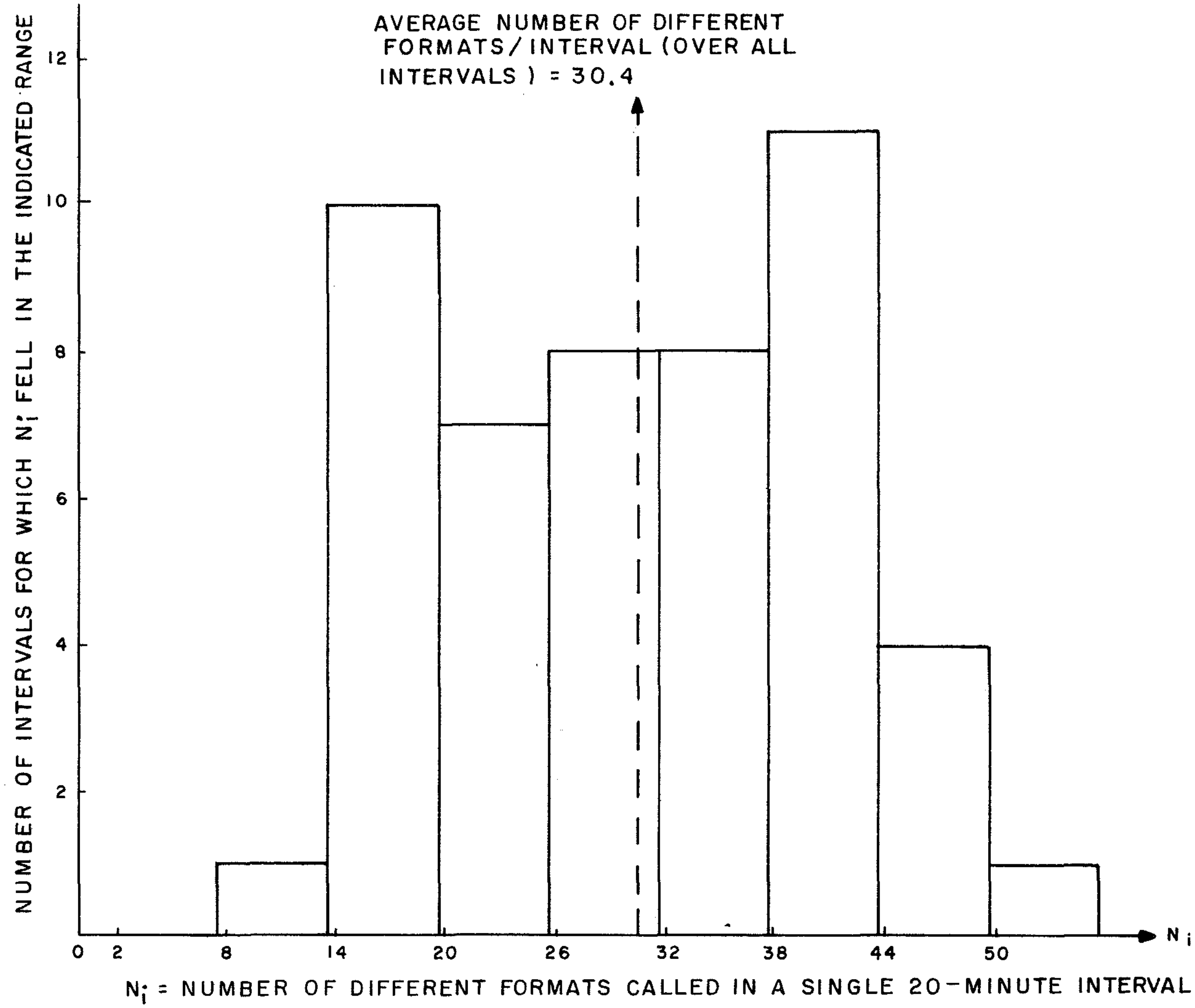

Figure 6. Distribution For N_i (MSK's Only, All Consoles)

Table 6

Values of S_j, by Functional Category

j	format	S_j
Flight Dynamics Formats		
1	0004	3
2	0005	2
3	0006	137
4	0007	166
5	0008	2
6	0009	3
7	0012	228
8	0013	6
9	0017	356
10	0018	1
11	0019	21
12	0020	18
13	0024	45
14	0025	21
15	0026	23
16	0027	90
17	0029	43
18	0031	12
19	0032	28
Guidance Formats		
20	0200	3
21	0201	5
22	0202	3
23	0203	2
24	0204	1
25	0205	31
26	0206	44
Guidance Formats cont.		
27	0208	7
28	0209	1
29	0212	3
30	0213	27
31	0214	36
Retrofire Formats		
32	0301	21
33	0302	17
34	0303	110
35	0304	2
36	0305	2
37	0306	5
38	0307	23
39	0308	0
40	0309	0
41	0310	0
42	0311	3
43	0312	8
44	0315	0
45	0317	13
GNC Formats		
46	0400	7
47	0401	1
48	0402	1
49	0460	32
50	0461	17
51	0462	7
GNC Formats cont.		
52	0463	15
53	0464	31
54	0465	3
55	0466	1
56	0470	3
57	0471	0
58	0473	1
59	0474	0
60	0475	0
61	0476	0
62	0480	17
63	0481	21
64	0482	8
65	0483	9
66	0484	9
67	0485	7
68	0490	0
69	0491	0
70	0492	0
71	0493	0
72	0494	0
73	0495	0
74	0500	3
75	0501	5
76	0502	1
77	0503	4
78	0504	3

Table 6 cont.
Values of S_j, by Functional Category

j	format	S_j
GNC Formats cont.		
79	0551	3
80	0552	4
81	0557	1
82	0560	18
83	0561	16
84	0562	1
85	0563	3
86	0564	3
87	0570	0
88	0571	0
EECOM Formats		
89	0602	3
90	0603	2
91	0604	2
92	0605	1
93	0606	0
94	0607	1
95	0609	1
96	0622	1
97	0626	2
98	0627	1
99	0628	16
100	0629	2
101	0630	1
102	0700	4
103	0701	4
104	0702	4
EECOM Formats cont.		
105	0703	2
106	0704	2
107	0705	2
108	0706	4
109	0707	16
110	0708	5
111	0709	1
112	0711	3
113	0712	22
114	0713	3
115	0716	2
116	0717	3
117	0718	2
118	0719	2
119	0721	31
120	0722	5
121	0723	3
122	0726	24
123	0727	2
124	0728	2
125	0729	3
126	0734	1
127	0735	0
128	0736	0
129	0737	3
130	0738	0
131	0739	0
EECOM Formats cont.		
132	0743	0
133	0744	3
134	0745	0
135	0746	0
136	0773	0
Life Systems Formats		
137	0800	1
138	0801	2
139	0802	2
140	0803	6
141	0807	0
142	0808	0
143	0809	1
144	0810	1
Spacecraft Communicator Formats		
145	0902	49
146	0903	6
147	0904	33
148	0905	105
149	0906	26
150	0908	4
151	0909	12
152	0910	18

Table 6 cont.
Values of S_j, by Functional Category

j	format	S_j
AGENA Systems Formats		
153	1000	55
154	1001	11
155	1002	6
156	1003	14
157	1004	28
158	1005	15
159	1006	16
160	1007	8
161	1008	6
162	1012	0
163	1050	33
164	1051	14
165	1052	1
166	1053	0
167	1054	0
168	1055	0
169	1056	13
170	1057	4
171	1058	1
172	1059	0
173	1060	10
174	1061	0
175	1062	1
176	1063	1
177	1064	0
178	1065	0
179	1066	2

j	format	S_j
AGENA Systems Formats		
180	1067	0
181	1068	0
182	1069	0
183	1070	0
184	1071	0
185	1072	5
186	1077	1
187	1078	0
188	1079	0
189	1080	1
190	1081	15
191	1082	9
192	1083	0
193	1089	11
194	1090	18
195	1091	5
Guidance & Control Formats		
196	1100	44
197	1101	4
198	1102	1
199	1103	15
200	1104	5
201	1105	1
202	1106	3
203	1107	2
204	1110	16

j	format	S_j
Propulsion Formats		
205	1200	30
206	1201	4
207	1202	0
208	1203	9
209	1204	3
210	1205	2
211	1211	0
212	1212	1
213	1213	1
214	1215	0
215	1216	0
216	1222	33
217	1223	18
ELS & Rendezvous Formats		
218	1230	38
219	1231	18
220	1232	12
221	1233	19
222	1234	5
223	1235	2
224	1236	2
225	1240	26
226	1241	7

Table 6 cont.
Values of S_j, by Functional Category

j	format	S_j
Booster Systems Formats		
227	1300	12
228	1301	10
229	1303	5
Recovery & Weather Formats		
230	1450	26
Network Operations Formats		
231	1480	0
232	1481	0
233	1482	0
234	1483	0
235	1484	1
236	1485	0
237	1516	0
238	1517	1
239	1518	0
240	1519	0
241	1520	0
242	1521	0
243	1522	0
244	1523	0
245	1524	18
246	1525	0
247	1526	0
248	1527	0
249	1528	0
250	1529	0

j	format	S_j
Network Operations Formats cont.		
251	1530	0
252	1531	0
253	1532	0
254	1533	0
255	1534	0
256	1535	0
257	1536	0
258	1544	0
259	1545	0
260	1546	0
261	1547	0
262	1548	0
263	1549	0
264	1550	0
265	1551	0
266	1552	0
267	1555	0
268	1556	0
269	1557	0
270	1558	0
271	1559	0
272	1560	0
273	1561	0
274	1562	0

j	format	S_j
RTCC Formats		
275	1570	55
276	1572	84
277	1573	4
278	1574	69
279	1575	11
280	1576	9
281	1579	42
282	1580	31
283	1581	2
284	1582	7
285	1583	222
286	1584	210
287	1585	0
288	1593	12
289	1594	8
290	1595	6
291	1596	5
292	1598	6
293	1599	35
294	1600	41

A detailed picture of how S_j varied over the various formats is given by Figure 7. Curve A is a distribution of S_j (histogram), showing the number of formats (and percentage of all formats) which had values of S_j in certain ranges. For example, it shows that 271 formats (or 92% of all formats) had an S_j between 0 and 34, inclusive; i.e., their number of calls varied between 0 and 34. Thus only 8% of the formats were called more than 34 times. A more detailed picture is given by Curve B, which covers only values of S_j up to 20, but which employs a unit increment for S_j. Because of this, Curve B shows exactly how many formats (also expressed as a percentage of total formats) were called 0 times, 1 time, 2 times, etc. The average number of calls per format, over all formats, is 13 (dashed line on Curve A). Curve B indicates that 90 formats were never called, 33 were called once, 25 were called twice, etc. The curves fall off rapidly with increasing S_j; for values of S_j above 18 there are never more than 4 formats having one of the observed values of S_j and above 55 never more than 1 format having one of these observed values.

If the number of calls per format, S_j is multiplied by the number of formats having that same value of S_j, the result is total number of MSK calls (for all formats having S_j calls) during the mission. This quantity is plotted versus S_j in Figure 8. The result is a scatter diagram of points, which shows, for example, that there were 99 calls for formats which were called exactly 33 times each during the mission (solid point), i.e., there were 3 such formats. The largest number of calls was 356; these were for a single format (format 0017). The smallest number of calls was 19, again, these were for a single format (format 1233). If there were only one format having any given value of S_j, the points would all fall on a straight line having unit slope. There are many such points; these are connected by a dashed line to form a lower boundary for the set of points. The fact that all points above $S_j = 55$ fall on this boundary simply illustrates the last phrase of the preceding paragraph. The larger the slope of a line from the origin to a given point, the larger the number of formats having that value of S_j. The largest such slope is for the first point ($S_j = 1$). Here the curve shows that there are 33 calls for formats called only once. Thus there are 33 such formats, which agrees with Figure 7.

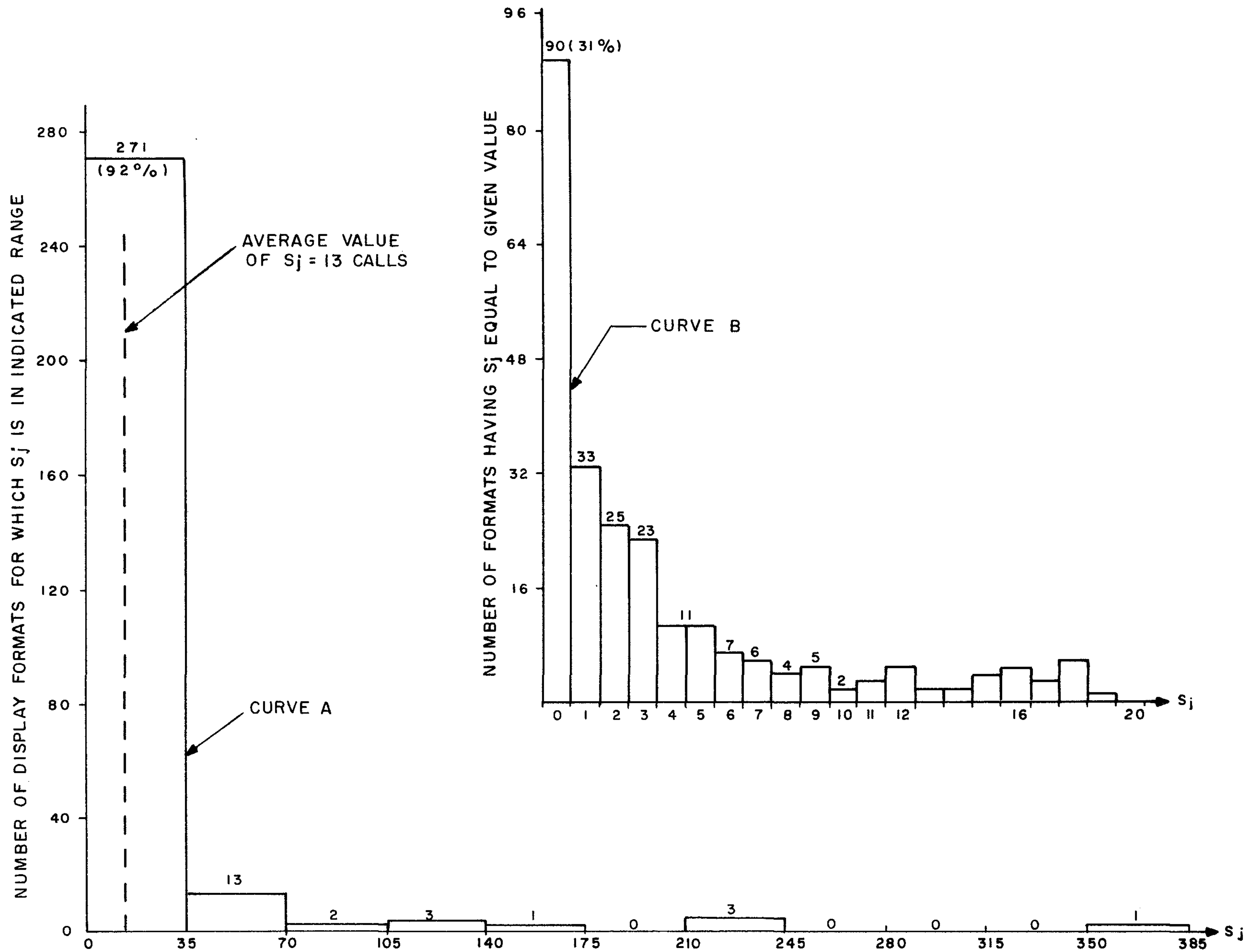

Figure 7. Distribution Of Number Of Calls Per Format (S_j)

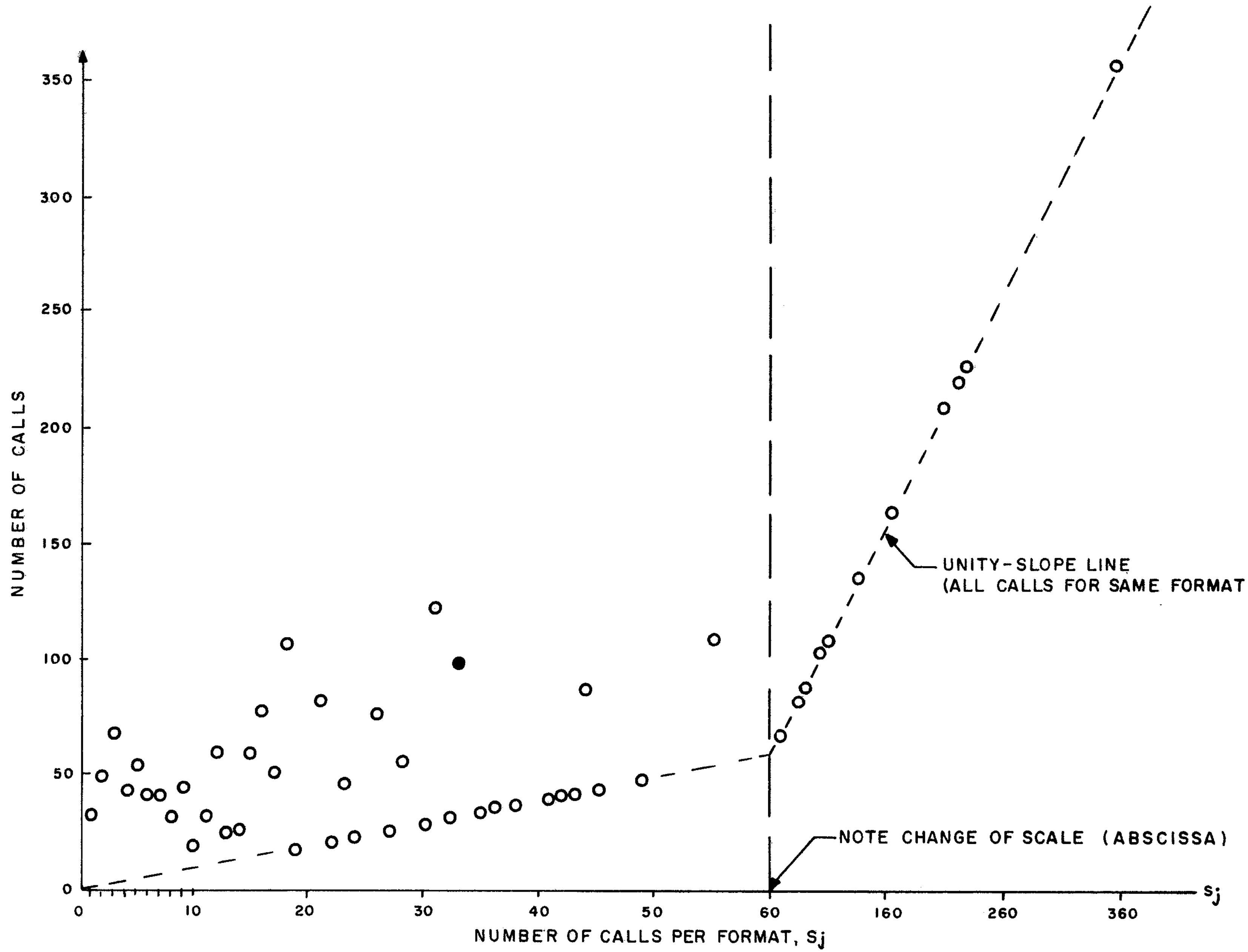

Figure 8. Total Number Of Calls (MSK's Only) For All Formats Having The Indicated Number Of Calls

Analysis by Functional Groups of Displays

When the various display formats are considered in terms of functional groupings (see Table 6), some interesting comparisons may be made among the fifteen groups of displays. Figure 9 shows the extent to which the available displays in each group were used (at least once), expressed as a percent usage (not including DRK requests). This was calculated for each group by dividing the number of displays used (at least once), by the number available in that group. As can be seen, 7 of the groups were used 100%, i.e., every display in these groups was called. The usage diminishes to about 63% as the next 7 groups are considered, and is only 4.5% for the last group (Network Operations). In the latter group, 42 of the 44 displays available were never called. From the curve, (Figure 9), the groups of displays fall into three fairly distinct sets: 8 groups (Flight Dynamics through RTCC) experienced usage equalling or approaching 100%, 6 groups (Life Systems through AGENA Systems) experienced usage averaging about 70%, and 1 group (Network Operations) had very low usage, approaching 0%. The overall utilization (all groups) is 69%, i.e., 69% of the 294 formats were called at least once. If the first call for a format is assumed to be for checking purposes, this utilization factor drops to 58% of the formats which were called for "operational" use (called at least twice).

Within each functional group, the displays experienced various numbers of calls, ranging from zero upwards. There are also various numbers of displays in each group, as can be seen in Table 6. One measure of activity of displays in various groups is the average (over all formats) number of calls per format. This is plotted for each group in Figure 10. The group having highest average format activity here is Flight Dynamics; this group also had 100% usage, from Figure 9. The group with lowest average activity is Network Operations; this group also had the lowest percent usage from Figure 9. There is fairly high correlation between the rank-order of a group in Figure 10 and its rank-order in Figure 9, i.e., high percent usage tends to be associated with a large number of calls/format, and vice versa. The calls/format curve in Figure 10, however, does not exhibit the 3 distinct ranges of values found in Figure 9; instead, it is a fairly smooth curve which is approximately negative - exponential in shape.

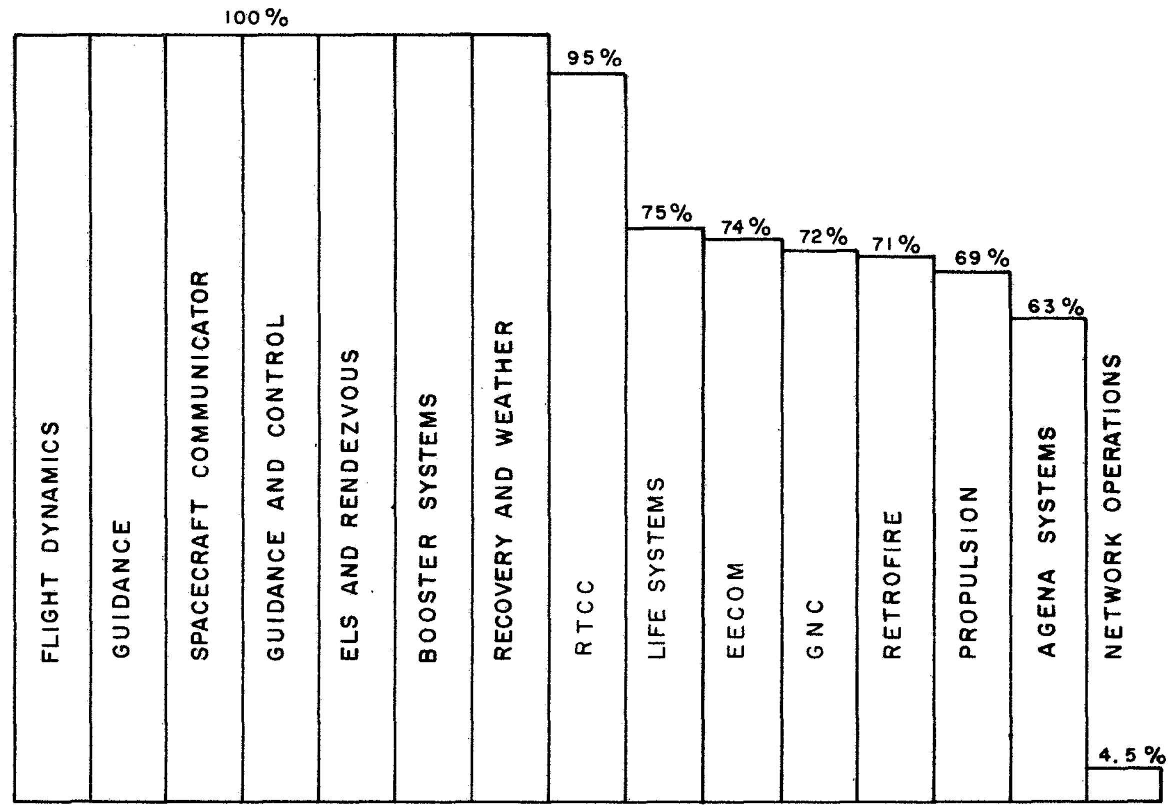

Figure 9. Percent Usage Of Available Formats By Functional Group, i.e. Number Of Formats Called (At Least Once) Divided by Number Of Available Formats (MSK's Only For GT-8)

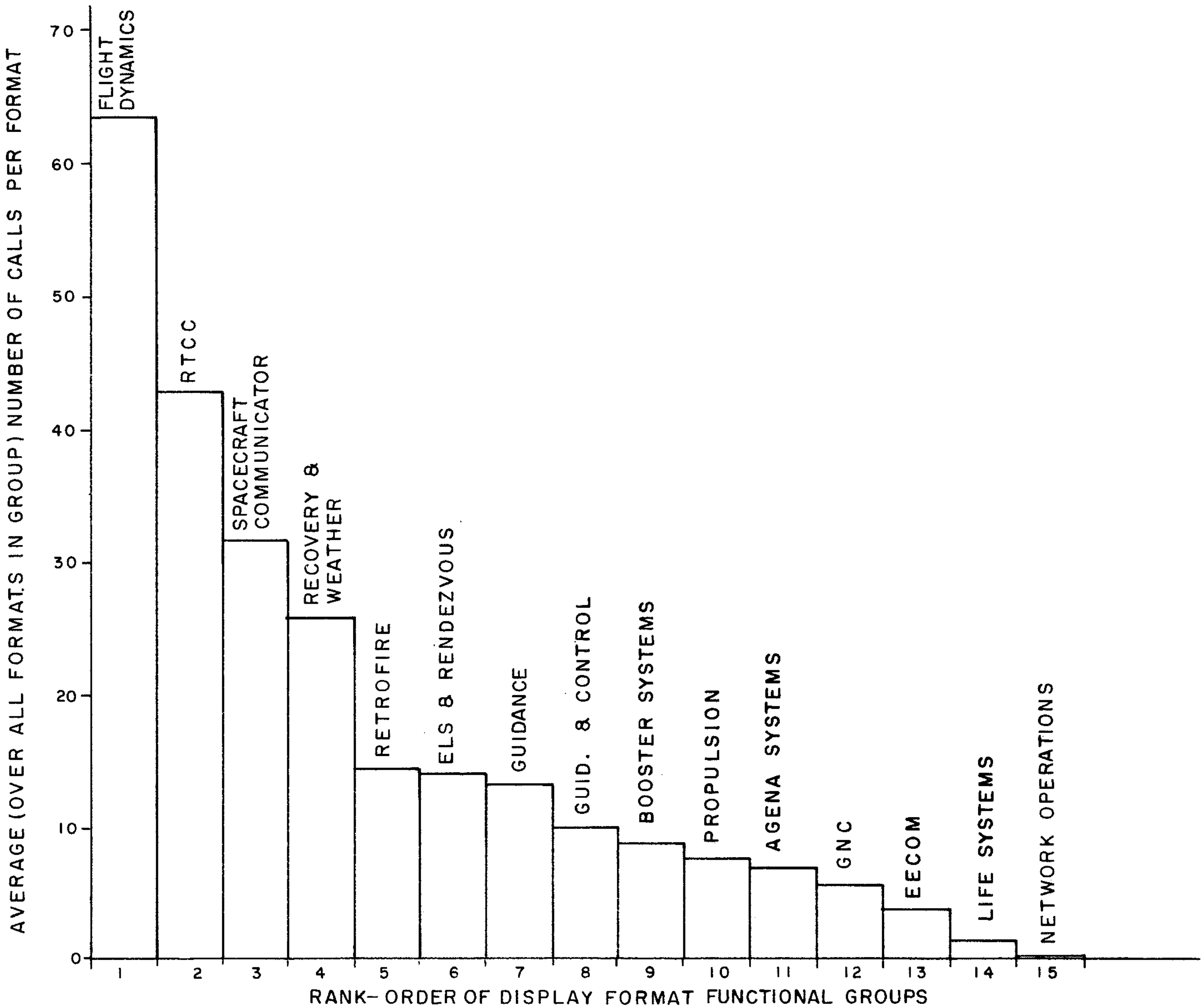

Figure 10. Average (Over All Formats In Group) Number Of Calls Per Format. Rank-Ordered By Functional Groups (All Consoles Requests Via MSK Only)

The average number of calls per format over all groups is 3823/294 = 13 calls/format, as indicated earlier on Figure 7. This average value, as well as the values for individual groups of formats, tends to be low because of the inclusion of formats having zero calls. If these are excluded, the values of Figure 10 are quite different in some cases, since the quantity being calculated is now the average number of calls per format <u>for those formats which were used</u>. For example, the format activity for EECOM displays goes up to 49 calls/format, from the 4 of Figure 10, and for GNC displays, the activity goes from 6 to 82. The overall average number of calls per format rises from 13 to almost 19 if formats having $S_j = 0$ are excluded. This effect is illustrated in Table 7, where the rounded calls/format are given for both inclusion of unused displays (i.e., the ordinates for Figure 10) and exclusion of unused displays.

Table 7

Average Number of Calls per Format When Excluding Formats Never Called

GROUP	CALLS PER FORMAT (incl. S_j=0)	CALLS PER FORMAT (excl. S_j=0)	GROUP	CALLS PER FORMAT (incl. S_j=0)	CALLS PER FORMAT (excl. S_j=0)
Flight Dynamics	63	63	Spacecraft Communicator	32	32
Guidance	14	14	AGENA Sys.	7	11
			G & C	10	10
Retrofire	15	20	Propulsion	8	11
			ELS & R.	14	14
GNC	6	82	Booster Sys.	9	9
			Recov. & Weather	26	26
EECOM	4	49	Network Ops.	0	1
			RTCC	43	45
Life Systems	2	2			

Analysis of "Clear" Requests and Errors

Further information concerning the dialing of MSK display requests (not tabulated in Table 6) was obtained by counting the number of "clear monitor" requests, i.e., the number of calls for "format" 0000. During the entire mission, there were 177 such requests. Also, a number of requested "formats" appearing on the DRIP printout turned out not to be legally - assigned format numbers; these are either machine errors or else represent human errors in dialing up displays (e.g., dialing 0011 instead of 1100). Assuming that all of them fall in the latter category, there were 147 such "mistakes" in dialing. Thus, the total number of MSK - dialed requests, using the display-request mode was 4147*, i.e., the sum of 3,823 valid display requests, 177 "clear monitor" requests, and 147 invalid display requests. These categories represent, respectively, about 92%, 4%, and 4% of the total number of requests.

Limitations on Conclusions

Conclusions drawn from this display format analysis are limited to some extent in their validity by the following factors, some of which have already been mentioned.

- Information of a temporal nature (exact time of request, "up" time or duration of a display, etc.) was used only to the extent of considering very gross time intervals, i.e., twenty minutes. This introduces an averaging effect which obscures the rapid changes that sometimes take place in the state of the display system. Such an interval is sufficiently short, however, to exhibit the long-term variations which take place during the mission.

- Only MSK display requests were analyzed; DRK requests were not included. The numbers and values quoted in the analysis are not to be considered as completely characterizing GT-8 display request activity.

*The equivalent number obtained in the module activity study was 4180; considering that these were obtained by different procedures and different people via manual reduction of a large amount of data, the two numbers agree to a remarkable extent (within about 1%).

They are presented to indicate the nature of the procedures for data acquisition and handling and to show the kinds of conclusions that will be possible if these procedures are used in a more comprehensive study effort.

- To the extent that a display request is not necessarily identical with a D/TV channel assignment, analysis of requests is not the same thing as analysis of channel assignments. The presence of multiple requests for the same display, as well as the generation of displays in some channels as a result of prior requests, means that the number of requests for different formats in a given interval is not equal to the number of channel assignments made during that interval, much less to the number of channels in use at any particular instant. Nevertheless, there is a rough correlation between these quantities, which gives some indication of demand for channels.
- These sample conclusions apply, strictly - speaking, only to the GT-8 mission. They can be extrapolated to other missions only to the extent that such missions are similar to GT-8 in complexity, mission phasing, and nature of displays used.
- The information content and arrangement of the different display formats was not considered, and hence no conclusions can be drawn as to the <u>types</u> of displays which can be expected to have low (or high) usage. For example, certain types of data may never have been needed because of the unexpectedly early termination of the mission; this might explain the absence of calls for some of the displays. The relatively-low demand for other displays might have been due to redundancy in data content, i.e., if two or more displays contain the same given piece of data, then, as far as access to that datum is concerned, one would expect requests to be divided among the displays, thus lowering the demand for each.
- No information as to which displays were designed for use only during one or a few mission phases was available, and all displays were treated the same on this basis.
- Information relative to which console called which displays was not abstracted from the matrix.
- The fact that many displays were called only once, and viewed only for a short time, indicates that these displays were not being used in the normal manner. Since such calls were included in the analysis, they tend to distort any conclusions as to the relative usefulness of various formats. At the same time, their inclusion makes more valid any conclusions as to hardware/software loading in the system.

Conclusions

Subject to the foregoing limitations, and based on the previously presented curves and data, the following types of statements seem reasonable;

- The average value of N_i (about 30 different formats requested in one twenty-minute interval) does not seem to be cause for alarm, as far as channel saturation is concerned. The occasional short-duration peaks in the time history of N_i indicate occasional channel saturation, thus supporting the conclusions of the channel saturation analysis.
- The very large variation in S_j over the various display formats (ranging from zero calls to 356 calls) suggests the possibility of decreasing the computer core memory capacity required to store and process displays, and hence of decreasing equipment costs. This could be done by making the less-frequently used displays less readily available, in some sense. In the extreme, those formats which can reasonably be predicted to have very small or zero usage could be considered candidates for removal from the system entirely, thus freeing CPU and core storage capacity. A more reasonable approach might be to store such displays on disk or drum, which is less expensive than core; the resultant savings in cost might more than compensate for the increased response time for this class of seldom - called displays.
- The number of mistakes made in dialing displays via MSK's is not large, on a percentage basis, and does not contribute significantly to CPU time in the computer.
- The relatively small number of "clear monitor" requests (an average of roughly 3 per console during the 15-hour mission) indicates that some displays possibly are being left on the monitor screens after they cease to be of value to a flight controller. This tends to shorten the life of the charactron tubes used for generating the displays, which leads to increased failure rate and higher maintenance costs. The precise extent to which this situation may exist cannot be determined from the data used in this analysis.
- There was not a highly significant difference among functional groups of displays insofar as usage is concerned; the percentage of available displays called at least once varied over a range of 100% to 63% if the one very low group (Network Operations) is excluded. This would indicate that the percentage of low-probability-of-use displays is not too greatly different from one group to

another, i.e., that the design philosophy used in designing the various groups is very roughly the same.

- The average number of calls per format varies over a wide range for the various functional groups of formats. The same comments apply here as apply to the wide range of variation in S_i itself. However, a remedy for low activity formats is potentially available within each functional group (this remedy is probably not available for the formats as a whole). If one assumes that the information carried within the displays of a functional group is by and large, not duplicated in any other functional group, than any major redundancies in displayed data must occur within groups and not across groups. In the case where such redundancies (duplicated data) occur in low-density displays, the redundancies may be eliminated by combining one or more displays into a single format. This is more feasible, from display design and display intelligibility viewpoints, when done within a functional group instead of across functional groups. It would have the effect of reducing the number of formats and increasing the average activity of the formats, i.e., one would not expect as great a variation in format activity. It should also result in reducing storage and update requirements on the computer (to the extent that redundant data is eliminated) as well as increasing the utilization of the core buffers in the D/TV channels. Last, but not least, it should tend to reduce the demand for D/TV channels, since a single channel could then be handling the data formerly requiring two or more channels.
- The time variation of display system parameters such as N_i is irregular and unpredictable, at least for the shorter-term fluctuations. This apparently random variation implies that such factors as channel demand may best be treated as random variables, i.e., it implies a statistical approach to the analysis and prediction of display system behavior.

TOTAL CONSOLE MODULE ACTIVITY ANALYSIS

Purpose

The purpose for analyzing total console module activity (i.e., the number and types of pushbutton actions by operators) was to reveal the nature and variation of D/C system activity during the GT-8 mission, as well as to form a basis for examining a number of missions, to determine load trends on the display system. Included is the objective of determining the relative usage of manual select keyboards and display request keyboards and of determining preference between the two display-access modes (i.e., display request mode and TV channel request mode).

Procedure

Module activity data was obtained through the use of the Philco DRIP program. The result was a computer printout containing over 27,000 lines for the GT-8 mission, and covering slightly under 17 hours (this includes about 2 hours of pre-mission and post-mission time).

This computer printout was reduced manually to a summary tabulation of operator input actions.

Results

The summary tabulation of input actions for 50 time intervals of 20 minutes each is presented in Table 8

The actual number of actions of each type is entered for each period, with the various types of MSK inputs (format requests, channel requests, and total requests) grouped for comparison. The appropriate actions are summed horizontally for each interval to obtain total display format requests, total actions, and (by the use of conversion factors) total words of computer input; these quantities appear in the last three columns. All columns are summed at the end of the table to give grand totals (over the entire mission) in each category. The grand totals for actions of each type is also expressed as a percent of all pushbutton actions.

The table reveals that the forced display keyboard (FDK), phase control keyboard (PCK), event sequence override (ESO), and summary message enable keyboard (SMEK) contribute only 2.53 percent of all actions, and that most of these actions occurred during the first 20 time intervals (which mainly cover the launch periods). FDK actions account for most of the 2.53 percent, and subsequent investigations of the printouts reveal that these FDK tabulations probably do not represent a true count of operator actions. The printouts indicate that the same FDK actions occur many times within a matter of seconds.

Table 8

TOTAL CONSOLE MODULE ACTIVITY TABULATION - Page 1 of 3

							MSK Manual Selection Keyboard					
Time Int.	FDK Forced Display Keyboard	PCK Phase Control Keyboard	ESO Event Sequence Override (2 Words)	SMEK Summ.Message Enable Keybd. (2 Words)	ESW Equipmt. Status Word (No Opr. Action)	DRK Display Request Keyboard (Display Format Requests)	Display Requests	TV Chann. Reqst.	Total MSK	Total Displ. Format Reqst.	Total Words	Total Pushbutton Actions
1	32	1	16	0	5	24	42	135	177	66	271	250
2	32	1	6	2	0	11	32	293	325	43	385	377
3	2	0	6	2	0	8	33	219	252	41	278	270
4	0	0	0	0	1	51	38	205	243	89	295	295
5	38	1	2	0	3	23	34	357	391	57	460	455
6	14	0	8	0	2	12	29	369	398	41	442	432
7	1	2	6	1	0	20	12	530	542	32	579	572
8	39	2	18	2	14	68	59	825	884	127	1047	1013
9	2	1	12	6	4	32	43	575	618	75	693	671
10	16	1	0	0	5	69	131	701	832	200	923	918
11	19	0	0	1	3	23	96	764	860	119	907	903
12	2	1	8	0	2	19	101	683	784	120	824	814
13	35	0	18	3	0	28	87	637	724	115	829	808
14	30	1	26	7	0	40	154	769	923	194	1060	1027
15	0	0	0	0	0	54	95	570	665	149	719	719
16	33	0	0	0	0	20	117	442	539	137	592	592
17	1	0	0	0	0	23	122	562	684	155	708	708
18	35	0	0	7	3	41	111	415	526	152	619	609

Table 8

TOTAL CONSOLE MODULE ACTIVITY TABULATION - Page 2 of 3

Time Int.	Forced Display Keyboard	Phase Control Keyboard	Event Sequence Override (2 Words)	Summ. Message Enable Keybd. (2 Words)	Equipmt. Status Word (No Opr. Action)	Display Request Keyboard (Display Format Requests)	Manual Select Keyboard Display Request	Manual Select Keyboard TV Chann. Reqst.	Manual Select Keyboard Total MSK	Total Displ. Format Reqst.	Total Words	Total Pushbutton Actions
19	9	0		2	6	65	150	326	476	215	560	552
20	0	0	1	0	1	49	112	246	358	161	410	408
21	3	0	0	0	7	71	122	306	428	193	509	502
22	15	0	0	0	2	47	93	349	442	140	506	504
23	4	0	0	16	0	53	158	480	638	211	727	711
24	14	0	0	2	0	52	168	495	663	220	733	731
25	0	0	0	0	0	39	147	441	588	186	627	627
26	4	0	0	0	0	38	87	450	537	125	579	579
27	6	0	0	0	6	47	123	675	798	170	857	851
28	0	0	0	2	0	42	144	553	697	186	741	739
29	0	0	0	0	0	54	113	490	603	167	657	657
30	0	0	0	0	0	32	83	291	374	115	406	406
31	5	0	0	0	0	29	83	522	605	112	639	639
32	8	0	0	0	0	33	129	356	485	162	526	526
33	5	0	0	0	0	25	88	400	488	113	518	518
34	9	0	0	0	6	14	68	273	341	82	370	364
35	0	0	0	0	0	18	100	298	398	118	416	416
36	16	0	0	0	0	29	78	462	540	107	585	585

Table 8

TOTAL CONSOLE MODULE ACTIVITY TABULATION - Page 3 of 3

Time Int.	FDK Forced Display Keyboard	PCK Phase Control Keyboard	ESO Event Sequence Override (2 Words)	SMEK Summ. Message Enable Keybd. (2 Words)	ESW Equipmt. Status Word (No Opr. Action)	DRK Display Request Keyboard (Display Format Requests)	MSK Manual Selection Keyboard: Display Request	MSK Manual Selection Keyboard: TV Chann. Reqst.	MSK Manual Selection Keyboard: Total MSK	Total Displ. Format Reqst.	Total Words	Total Pushbutton Actions
37	6	0	0	0	4	28	51	450	501	79	539	535
38	5	0	0	0	0	52	71	316	387	123	444	444
39	0	0	0	0	4	14	93	359	452	107	470	466
40	5	0	0	0	0	20	58	542	500	78	525	525
41	5	0	0	0	0	29	47	155	202	76	236	236
42	6	0	0	0	0	10	54	359	413	64	429	429
43	19	0	0	0	0	23	77	386	463	100	505	505
44	0	0	0	0	0	15	71	311	382	86	397	397
45	4	0	0	0	0	6	32	489	521	38	531	531
46	0	0	0	0	0	17	83	122	205	100	222	222
47	0	0	0	0	0	28	36	252	288	64	316	316
48	0	0	0	0	0	22	50	49	99	72	121	121
49	0	0	0	0	0	13	25	172	197	38	210	210
50	18	0	0	0	0	10	50	257	307	60	335	335
Totals:	493	11	127	53	78	1590	4180	20,563	24,743	5770	27,278	27,020
Percent of All Pushbutton Actions:			2.53			5.87	15.5	76.0	91.5	21.37		

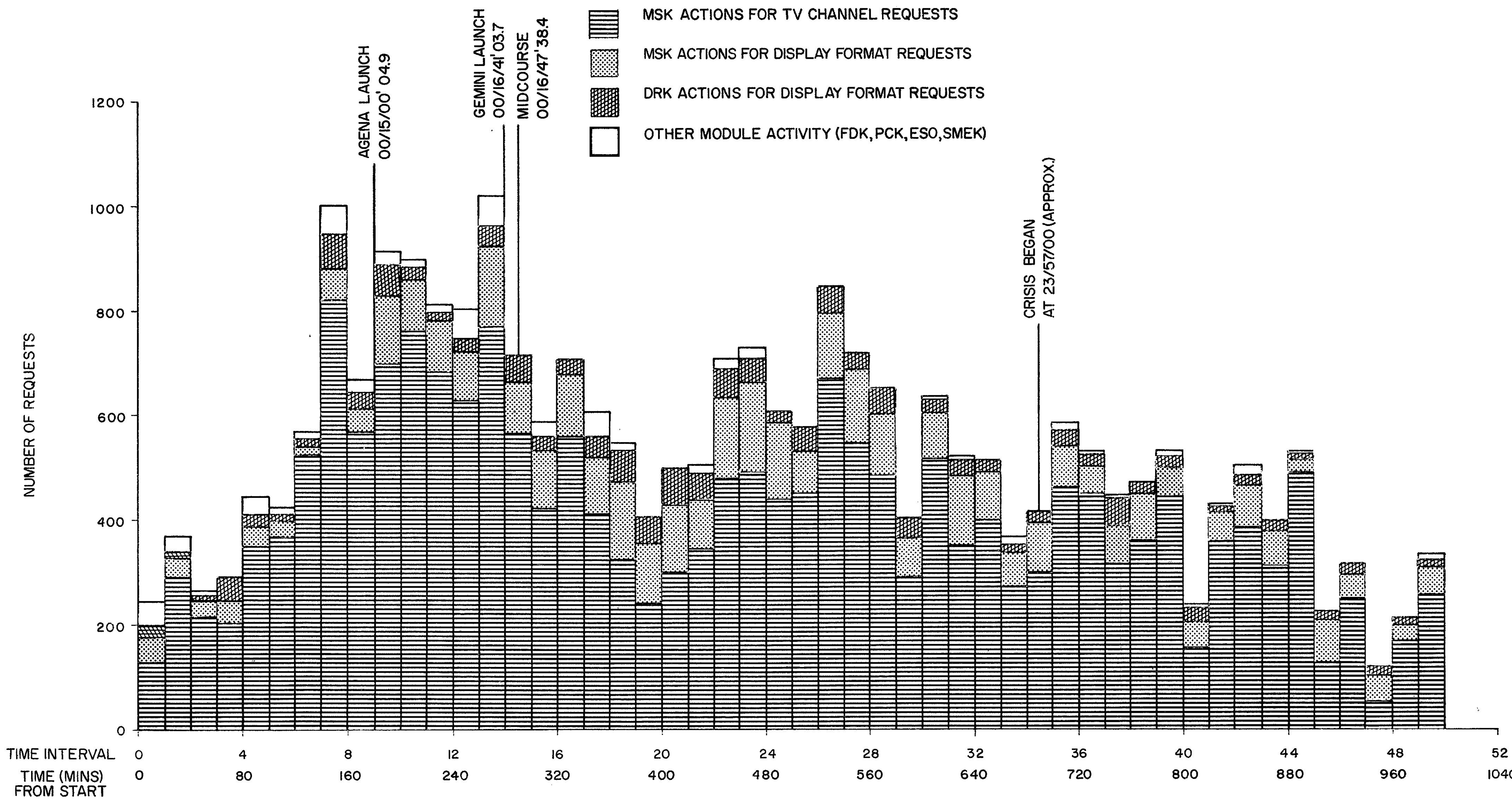

Figure 11. Total Console Module Activity For GT-8

Our interpretation is that controllers tend to keep the FDK acknowledge button (which is blinking) depressed from one to several seconds. The CIM loading study, page 68, indicates that the CIM is being used to less than two percent of capacity on a time-averaged basis and is almost always ready to transmit requests to the RTCC. This low load factor, and the fast scanning characteristic of the CIM mean that transmissions of FDK acknowledges from the same scan position can occur within milliseconds of each other. Thus if an operator depressed the FDK button for one second this could result in the RTCC receiving several of the same FDK acknowledgements, which appears to be the case. However, the relatively small number of FDK, SMEK, ESO, and PCK actions compared with other keyboard actions do not seriously affect the interpretations of this data (although as far as the RTCC and CIM are concerned these FDK actions do occur and must be serviced).

Table 8 allows a comparison of the MSK and DRK actions, and Figure 11 graphically shows the nature of these actions over the fifty time intervals. It is apparent that the bulk of the module activity occurs through the MSK (91.5 percent of all console pushbutton actions). This is to be expected, since there are approximately 62 MSK modules compared to 6 DRK, 2 PCK, 10 FDK, 2 SMEK, and 4 ESO modules.

Conclusions

The significant facts illustrated are that

(1) the MSK TV channel mode (which represents relatively little load upon the RTCC) is used most (76.0 percent of all pushbutton requests, or a total of 20,563 requests for the entire GT-8 mission).

(2) the MSK display format request mode is used for only 72.5 percent of the display format requests, or only about three times as much as the DRK is used, even though there are roughly ten times as many MSK modules as there are DRK modules.

(3) modules other than DRK and MSK place little demand on the display system.

A total console module activity analysis performed for several missions can serve the dual purpose of allowing comparisons of module activity within the various phases of a given mission, and also comparisons between different missions. It can also serve to determine the effect of increasing or decreasing the numbers and types of modules on the total console module activity for a mission. This should offer an insight into the effects of servicing multiple missions or of adding more consoles and controllers.

This type of study now requires a tedious manual effort to tabulate the data, but this can be improved by automating the procedure via computer programs. Another improvement in this analysis could be made by examining console activities within smaller time intervals. These improvements seem justified since this total console activity study, combined with a detailed study of activity on individual consoles, should provide one with most of the necessary data for a tractable model of the display system. By analyzing several missions, trend factors might be discerned which would allow judgments to be made on adequacy of equipment design and performance for future missions.

MSK VERSUS DRK USAGE ANALYSIS

Purpose

This analysis was a comparison of the use of display request keyboards (DRK) and manual selection keyboards (MSK) on those consoles containing both modules. The analysis was done to determine console operator preference between these devices for calling up display formats, as well as the effect of having a DRK on D/TV converter channel requests. This console operator preference, in conjunction with an increase or decrease in number of modules, could act to seriously affect the amount of D/TV channel saturation.

Procedure

Five of the six consoles containing both MSK and DRK modules were analyzed through the use of DRIP printouts. The nature of this delog program limits to four the number of consoles about which data can be obtained in a single pass of the mission log tapes. For GT-8, this meant over two hours of computer time to obtain this data. Data on a fifth console was obtained from another study and it was not felt that the additional computer time required was justified for obtaining data on one more console.

The consoles analyzed were:

(1) Console 7 EECOM (Systems Engineer No. 1)
(2) Console 9 Agena Systems Engineer
(3) Console 11 Flight Dynamics Officer
(4) Console 13 Retro Officer
(5) Console 45A RTCC Telemetry Processor Controller

The GNC (Systems Engineer No. 2), console 8, contains a DRK but was not included in this analysis. The data was obtained by counting the number of dynamic display formats requested via the DRK, the number requested via the MSK, and the number of TV channel requests via the MSK. This count was made for each of the five consoles for the entire GT-8 mission.

Results

Figure 12 shows operator actions on DRK and MSK modules for five consoles containing both types of modules. In all five consoles, the DRK module was used most in calling up display formats. The DRK was used exclusively for requesting display formats in the case of EECOM, and almost exclusively in the case of the Flight Dynamics Officer. It is interesting to note that total activity for console 45A far exceeded the level of activity for any of the other four consoles; one reason for this seems to be a large amount of searching or rapid sequential pushing of display request buttons on the part of the operator. However, it should be noted that certain functions

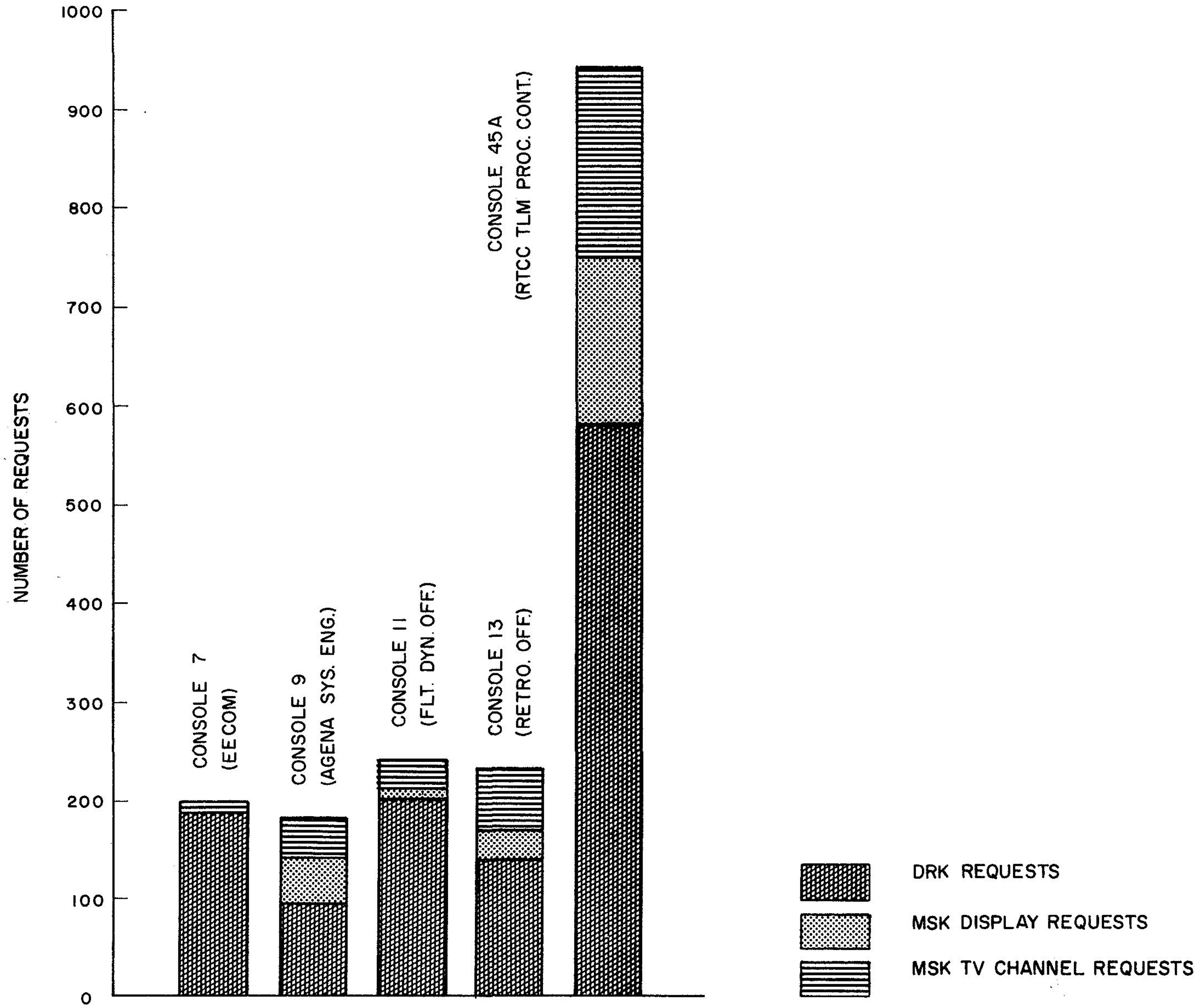

Figure 12. MSK Versus DRK Usage Summary

call for the rapid monitoring and checking of displays, i.e., the RTCC Telemetry Processor Controller, who has the function of monitoring computer-generated telemetry displays for consistency with input data, and consistency between MOC and DSC. He also monitors telemetry input data for missing data and validity. These functions may account for his rapid selection of display requests. Throughout these entire usage analyses a great deal of this type of request activity was noticed. This condition is characterized by multiple requests of displays for the same TV monitor within seconds. It was not uncommon to have on the order of a dozen requests, within 15 seconds, for displays to appear on the same TV monitor.

Conclusions

In general, many console operators are apparently searching through the entire repertoire of displays and TV channels at various times during the mission. A detailed investigation and analysis of operational procedures and operator functions could usefully extend the present analysis.

The relative activity of MSK and DRK modules located on the same console is apparent from the graph of Figure 12. Operators who have both modules show a significant preference for the DRK over the MSK module. It is interesting to note that in the total console module activity analysis (page 57) the overwhelming use of the MSK is devoted to calling up TV channels. This type of request mode has no affect on the D/TV converter channel load. But when an operator requests a display via the DRK or the display request mode of the MSK, the RTCC will assign the display, if it is not currently available on a channel, to a converter channel, if one is available. Thus display format requests have the effect of loading the display system by using up the limited number of converter channels. For the consoles analyzed in this study, the number of TV channel requests is small compared to the number of display format requests, whereas for all consoles, the number of TV channel requests exceeds the number of display format requests. Furthermore, possessors of DRK's make more display requests than other operators; from the total console module activity study the DRK's (which represent only about 10% of the modules capable of making such requests) are responsible for over 27 percent of such requests. One can conclude that any significant increase in the number of DRK modules would tend to increase the usage level of the D/TV converter channels and thereby increase the likelihood of saturation.

COMPUTER INPUT MULTIPLEXER LOADING ANALYSIS

Purpose

The purpose of this analysis was to determine the average CIM loading (i.e., CIM usage as a percent of total CIM capacity) for GT-8 and to establish a technique of analysis that can be applied to other missions. Additionally, it was hoped the results of such a study would be useful in suggesting means of evaluating a proposal that has been made to use some of the CIM scanning positions for the Communications, Command, and Telemetry System (CCATS)

Procedure

All input requests from the consoles are funneled to the computer through the Computer Input Multiplexer (CIM). The CIM is a high speed sequential scanning device containing 128 fundamental scan positions, each consisting of 8 fine scan positions, for a total of 1024 scan positions. The CIM scans at a rate of 40 microseconds per scan position. When a scan position contains a display request input, the CIM locks onto that position until it can transmit the request (in 36-bit serial words) to the RTCC, and then proceeds to the next sequential scan position. The maximum transmission rate to the RTCC is 2500 bps. There are currently about 70 fundamental scan positions assigned.

The procedure for obtaining the loading data was to tabulate the total number of input words to the CIM for each of fifty 20-minute time intervals. This data was derived from the same computer printouts used in the total console module activity analysis (Page 57). The number of words was then divided by 20 to give an average rate, in words per minute, for each interval. These were compared to the maximum such average rate which the CIM can handle (4167 words per minute, at the present computer input rate).

Results

Figure 13 shows CIM output rate characteristics for the entire GT-8 mission, in terms of average output rate in words per minute for each of the fifty 20-minute time intervals. Figure 13 is almost an exact replica of Figure 11 in the Total Console Module Activity Analysis; one can thus correlate the number of console input requests with percentage of CIM loading. As an example, 1,000 total module requests (time interval 8 on Figure 11) represent an average rate of slightly less than 53 words per minute (interval 8 on Figure 13), or approximately 1.3 percent of maximum CIM capacity.

Figure 14 is a distribution (histogram) of the fifty observed CIM rates (expressed as a percentage of the maximum CIM rate).

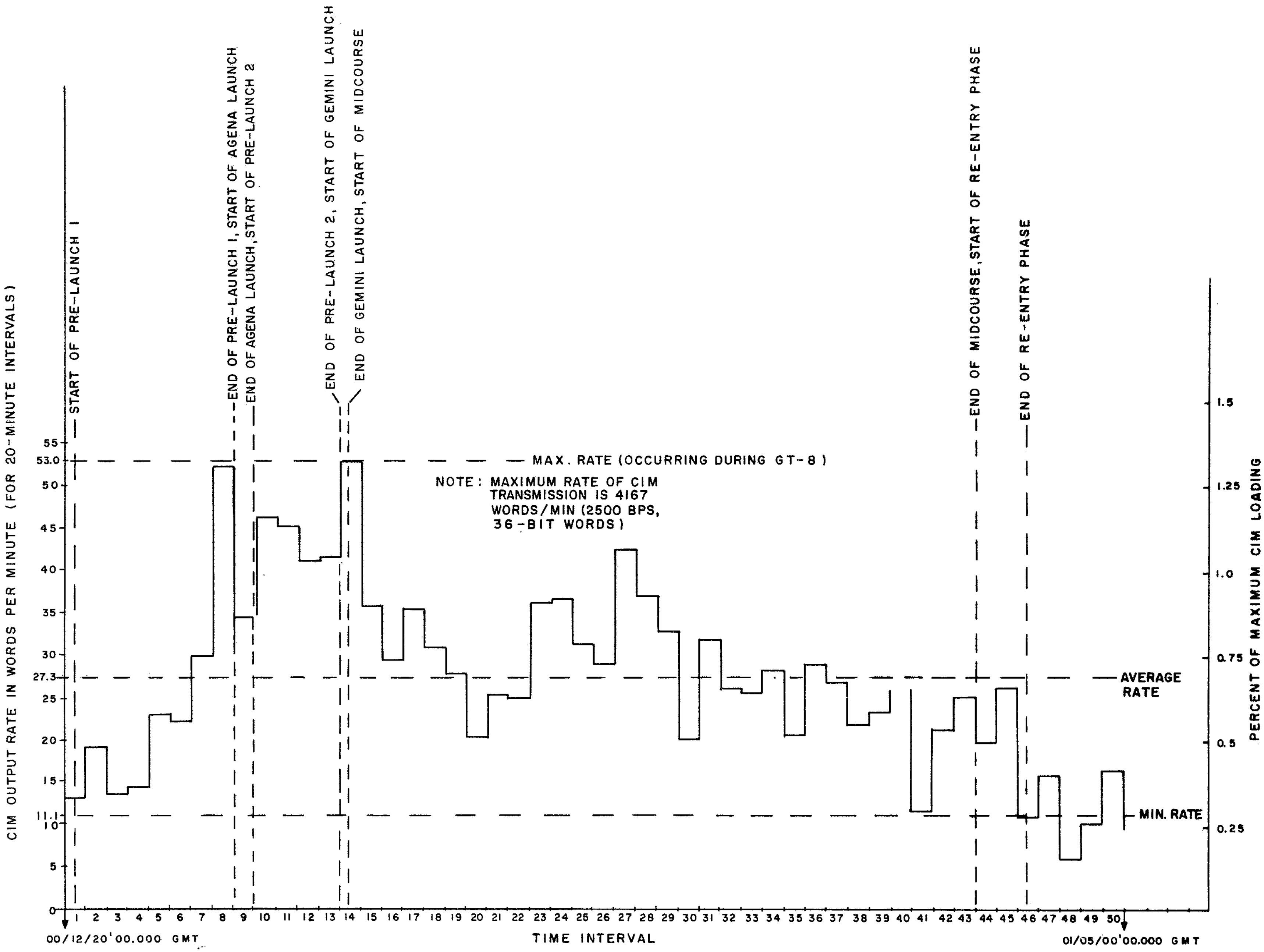

Figure 13. Computer Input Multiplexer Usage

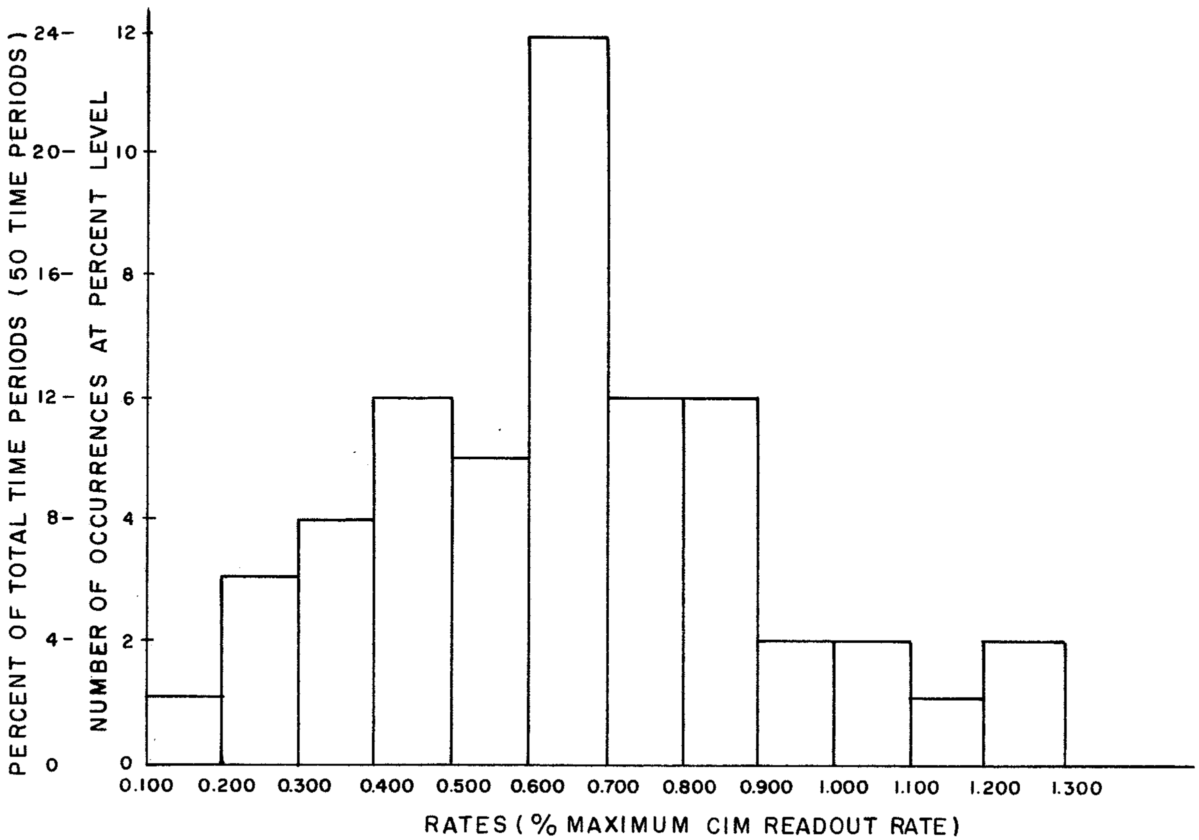

Figure 14. Distribution of CIM Output Rates

This distribution shows, for any of the given ranges of rates, the number of time intervals for which a rate in that range occurred (also expressed as a percentage of the total number of time intervals). The curve has a peak at the long-term average rate (calculated to be about 0.650 percent of total capacity).

The results clearly indicate that average CIM loading is very low. The maximum loading during any one 20-minute interval was 1.27 percent of maximum capacity or 53.0 words per minute, and the long-term average transmission rate was 27.3 words per minute compared to the maximum possible rate of 4167 words per minute.

Conclusions

The significance of the very low loading is that the CIM is essentially ready to transmit most of the time. This cannot be translated directly into a statement concerning the time delay suffered by a given request as it passes through the CIM, but the design characteristics of the CIM are clear and simple enough to permit theoretical calculation of time delays under worst case conditions (as done in section III). The largest number of words transmitted in any twenty-minute interval was 1060. If these had been the result of very closely-bunched input requests, a congestion situation would exist which could have caused a total CIM delay of up to 1.5 seconds for a given request. However, this would require that all 1060 requests be generated within roughly 15 seconds, a near-impossible situation for console requests.

The number of data samples used in this analysis is probably large enough to allow extrapolation of results to cases where additional scan positions are used, as long as these are used for the same type of inputs (mainly display requests) as at present. Thus one could expect that doubling the number of utilized scan positions, as a result of doubling the number of consoles, would double the average CIM rates; this would still leave the CIM essentially idle most of the time. The proposed use of 32 additional fundamental scan positions (or 256 fine scan positions) for CCATS is difficult to handle on this extrapolation basis, since the CCATS inputs may differ markedly (in terms of rate of occurrence) from console module inputs. One can only say that if the additional inputs are similar in nature to console inputs, the average CIM loading will increase from 0.65 percent to 2.4%; again, this gives little indication of expected time delays since the exact nature of receipt of CCAT inputs is not known at this time by the D/C analysts.

DIGITAL/TV CONVERTER CHANNEL OUTAGE STATISTICS

Purpose

A necessary part of any complete analysis of the display system is an analysis of equipment outage statistics for the converter channels. This follows from the fact that effective saturation of these channels can be caused by two factors: 1) The heavy use of these channels for servicing display requests, and 2) the physical unavailability of channels due to malfunction and failure. The objective of this study was to reveal the extent to which malfunctions contribute to channel saturation, and to obtain some idea of the availability of this part of the system during GT-8.

Procedure

The data needed for this analysis was available from the same DRIP printout used for the other usage analyses; namely, a time history of the equipment status words (ESW) entered into the RTCC. These ESW's show all changes in converter channel status (i.e., from operable to inoperable, and vice versa); these changes are identified as to channel and time of occurrence. From this data, information was extracted as to number and durations of outages and their distribution over the 28 channels, as well as to percent channel availability during the mission.

Results

The outage data as presented in Table 9 indicates that channel outages were limited to a few channels and were mostly of relatively short time duration. As can be seen, there is a high correlation between number of outages and total outage time (total "down" time) for a given channel. The worst channel, from both standpoints, was channel 18; this channel experienced 8 outages and had a total outage time of 27 minutes, 13 seconds (these outages may not be necessarily due to equipment malfunctions). However, even this worst channel was available for use during approximately 99% of the observation time. Some idea of the availability of this part of the system can be obtained from the table (duration of various conditions in terms of number of outages simultaneously occurring). From these figures it can be seen that there were no outages for 92.3% of the mission duration. There were never more than two channels out at the same time.

Conclusions

It appears that there were no serious difficulties in keeping the converter channels in operation. The outages do not noticeably

Table 9

Digital/TV Channel Outage Statistics (ESW)

		Duration of Condition	Duration As % of Mission
(a)	Condition 0 (no outages)	13 hr.,55'13	92.3 %
(b)	Condition 1 (1 outage)	1 hr., 4'43	7.2 %
(c)	Condition 2 (2 outages)	0'21	0.5 %
			100.0 %

66% of the outages are less than 1 minute duration
17% of the outages lie between 1 and 5 minutes duration
17% of the outages lie between 5 and 12 minutes duration

Channel Number	18	01	11	05	14	07	17	02	21	15	All Other
Durations of Outages	0' 3	0' 3	0' 1	0'10	0'13	0'28	0'14	0' 7	0' 5	0' 1	0'0
	0' 9	0'35	0'11	0'14	0'51	0'28	0'14	0' 7	0' 5	0' 1	
	0'15	0'36	0'43	3' 6	1'04						
	0'32	1' 4	1'33	3'30							
	0'46	3'18	4'20								
	5' 1	9'27	6'48								
	8'48	10'52									
	11'39	25'55									
	27'13										
Number of Outages	8	7	5	3	2	1	1	1	1	1	0
Total Outage Time	27'13	25'55	6'48	3'30	1'04	0'28	0'14	0' 7	0' 5	0' 1	0

(Numbers below the lines are total outage times for various channels)

(Total outage time over all channels = 65'25 or 65.42 channel-minutes) affect the data or statistics of the other usage analyses and no further analysis of outages seems warranted for other missions, (except for one more mission to ensure that data for GT-8 was not an anomaly), unless equipment reliability decreases significantly (a condition which would be readily noticed during operations). The major conclusion is that the D/TV Converter is about 100% available for almost 100% of the time, and hence that channel saturation is caused almost entirely (when it occurs) by large demand on the system from console operators. Thus the remedy for the occasional channel saturation which occurs (if a remedy is needed) is simply to add more converter channels, rather than to try to increase the reliability of individual channels. This conclusion must be qualified by the fact that the data used were for a relatively short mission, and conceivably could have been different if based on failures during a long mission.

OTHER USAGE ANALYSES CONSIDERED

In addition to the foregoing analyses, several other studies were considered but, for various reasons, were not attempted. Brief descriptions of these appear below.

(1) Breakout by console of such data as number of different types of input actions and when they occurred, which display formats were retrieved and by what types of request actions, "up" time (on that console's monitor screens) of each format viewed, etc. A limited amount of console - specific information was derived in the DRK vs MSK analysis and in the analysis of the three Life Systems Consoles.

(2) Analysis of FDK use. This would include time histories of FDK out-of-limit alerts and operator responses thereto, as well as ratio of responses to alerts.

(3) Comparison of the functional group to which a console belongs with the functional group(s) to which the displays viewed at that console belong. This requires some feasible procedure for determining which displays were on which TV channels at which times, and would use data of the type described in (1).

(4) Determination of interarrival-time statistics for display format and TV channel requests, again using data of the type described in (1). This would include a comparison of these statistics from console to console, as well as specification of the aggregate statistics for all consoles.

(5) Tabulation, by display formats, of the number of console monitors displaying that format, as a function of time. This would yield, among other things, the total monitor-hours for each format.

(6) RTCC delay in processing a display request. By comparing the time of input of each request to the time of output response, the statistics of the RTCC processing delays could be determined.

(7) Time history and statistics of the number of D/TV channels in use, obtained from RTCC output data.

(8) Input word rates for the DDDSDD, as a function of time, obtained from the logged RTCC output data. This might also include an analysis of "on" time, duty cycle, etc., for various digital display lamps (event lights, etc.).

(9) Console output activity; i.e., the number of RTCC and other outputs to each console, as a function of time. Statistical analysis of such data should disclose the relative information load being applied to each console operator.

Some of the above analyses are recommended for future accomplishment in the final section of this volume.

SECTION V

SUMMARY OF CONCLUSIONS

SPECIFIC CONCLUSIONS

Based on the detailed conclusions given in SECTION IV and the CIM delay calculations in SECTION III, the following specific conclusions, in several categories, can be stated.

System Loading, Saturation, and Availability

(1) The Computer Input Multiplexer (CIM) was very lightly loaded, on an average basis, during GT-8 (at a maximum of 1.3% and an average of 0.6% of the CIM capacity). The average loading caused by the proposed addition of scan positions for CCATS can be absorbed readily, provided the loading characteristics of the CCATS inputs are similar to display request loading characteristics.

(2) Malfunctions of D/TV Converter channels were insignificant during GT-8, resulting in almost 100% hardware availability of this part of the display system.

(3) There was no conclusive evidence that saturation of the D/TV Converter during GT-8 (due to demands for displays by console operators) reached levels which would cause concern.

Module Activity

(1) The greatest percent of display-retrieval actions by console operators was accomplished via a request mode which produces relatively light loading on the system (TV channel-Request Mode).

(2) Of the six types of modules used by console operators to make input requests via the CIM, two (MSK and DRK) accounted for 97 percent of all requests during GT-8; hence these two types are of most interest from the standpoint of demand on the display system.

(3) Console operators, if they have a choice, prefer DRK's over MSK's for making display format requests. In addition, those DRK's installed for GT-8 accounted for a disproportionately large number of format requests. Hence the installation of more DRK's, as opposed to MSK's, will place relatively more load on the display system and increase the chances of saturation.

(4) The study of console module activity, on a time-of-occurrence basis, allows the projection and extrapolation of system

loads as a function of numbers of modules added to, or deleted from, the system. It can also provide the demand statistics necessary for predicting system delays in responding to operator requests.

Display Format Usage

(1) There was some evidence, in GT-8, of possible anomalies in display format usage, although this conclusion is based on limited data. These include, as examples, a large variation in the number of times each display format was called (both over all formats and over functional groups of formats), and indications in one study that the Life Systems functional group of consoles utilized very few displays belonging to that group while utilizing many more displays from other functional groups. If these anomalies are found to be typical through further study, this could indicate that reductions in display formats are possible by deleting some and/or combining other formats.

Time Delay

(1) The display system's delay in responding to a console operator's request is important from a performance viewpoint as well as being highly variable and dependent on several random factors. Calculated worst-case delays are intolerable; however, the display system's actual average delay probably is much closer to the best case (less than 4 seconds) than to the worst case. Even though all indications are that the worst cases seldom occur, their exact probabilities of occurrence are not now known. It should be noted that the statement concerning CIM adequacy for proposed CCATS use does not include delay as a consideration.

GENERAL OBSERVATIONS AND CONCLUSIONS

A number of somewhat more general observations and conclusions can be stated, not all of which are direct results of the various analyses performed. These are listed below under two categories.

System Hardware Characteristics

(1) All console operator interactions with the display system hardware are by means of mechanical devices such as pushbuttons, thumbwheel and toggle switches, and dials. At present, no use is made of the display surface as an input device, which can have advantages in certain cases.

(2) The hardware of the display system is very flexible, with its patching and inter-connection capabilities; this has both advantages and disadvantages. One disadvantage is the lack of standardized configurations from mission to mission. This tends to produce a documentation problem, as well as requiring significant time and effort in physically rewiring the system. A remedy which has been suggested is reconfiguration via computer software; the desirability of this approach, indeed the desirability of any change in flexibility, can be evaluated only by further study.

(3) The display system hardware is, by and large, special-purpose hardware, at least at the subsystem and major unit levels. It is computer-specific in at least a few ways, i.e., it will work without modification only with computers having a 36-bit word length, and having certain input and output rates. It is not designed to work with certain types of computers, e.g., those designed for time-sharing operation. None of these statements are meant as criticisms of the system. The circuits and techniques used throughout are quite standard, within each major unit.

(4) The ratio of capacity to average or peak demand probably varies to some extent throughout the display system. While some variation is to be expected, an excessive variation in this ratio indicates inefficiency of utilization of equipment. Whether the variation is within reasonable bounds was not determined in this study.

(5) Potential limiting factors on system performance include input factors such as the CIM or ACIM (number of scan positions, scanning rate, output transmission rates), computer processing factors (input/output rates, processing delay, priority structure for interrupts), and output factors such as the number of D/TV channels. Based on the limited results of this study, none of these potential trouble areas seem to be acting as "bottlenecks" with the present level of system usage. It is interesting to note that queuing can occur for the system in at least three places: at the input to the CIM, in the RTCC, and in the Video Scanner Control unit (storage of hardcopy requests).

System Analysis Factors

(1) Usage analysis of the sort done for this study is tedious and time-consuming, due to the large amount of manual labor involved.

(2) Certain facts arising from the usage data analysis are unexplained, e.g., the lack of peaks in display system activity during the crisis period of GT-8 and a significant number

of display formats having little or no usage during this mission. Such facts cannot be interpreted from log data alone; they require in addition a knowledge of operational procedures, human operator preferences, and understanding of the functions and needs of various Flight Controllers and console operators.

(3) The results of the usage studies indicate that they are of basic importance to both assessment of past operations and prediction of system performance during future operations (via providing the data needed to construct useful analytical models of the display system's operation).

(4) Many system parameters identified and studied in this analysis (e.g., D/TV channel saturation, the number of different displays called per unit time, average CIM rates, etc.) exhibit a variation with time which is essentially random. This implies a statistical approach in constructing the models mentioned in (4) above.

SECTION VI

RECOMMENDATIONS

Recommendations relative to the Display and Control system are given below in three major categories.

MODIFICATION OF PRESENT SYSTEM

Immediate and extensive redesign or modification of the C/D system is not justified by any evidence gathered in this study, and is not recommended.

This recommendation does not mean that relatively minor changes (e.g., addition of four to eight D/TV channels or assignment of some unused CIM scan positions to CCATS) should not be considered. At least one such minor change, an increase in the number of DRK modules, is contra-indicated by this study and should be avoided. The recommendation does mean that relatively major changes (e.g., a change in the method of generating displayed characters, or changes in the type and degree of centralization of display memory) should be made only as justified by quantitative evidence of need.

EXTENSION OF PRESENT STUDIES

It is recommended that the type of display system analysis begun under this contract and described in this report be continued. As part of the continuation, the analysis techniques developed here should be broadened, extended, and improved. More specific and detailed recommendations are given below.

Continuation of Established Analyses

Those analyses concerned with potential system problem areas (e.g., channel saturation and system response time) are recommended for long-term continuation, as follows:

(1) D/TV Channel Saturation Analysis. This analysis, in at least its present degree of development (measurement of RED/AMBER conditions) should be done for several past missions and for each new mission, primarily to detect any dangerous trends in channel saturation. The analysis can be made more effective for this purpose by improvements described later.

(2) Functional Console Group Analysis. This analysis, exemplified by the Life Systems Consoles study reported in SECTION IV, should be completed (analysis of all functional console groups) for GT-8, and should be done for enough other missions to establish whether there are significant anomalies in display format usage.

(3) Total Console Module Activity Analysis. This analysis, with improvements described later, should be performed for several past missions and for each new mission, primarily for the purposes of establishing trends in operator demand and determining the distribution of interarrival times for display requests. These factors should be of significant aid in predicting system response times for future missions.

It is recommended that other already-developed analyses be continued for at least one mission beyond GT-8, primarily for confirmation of GT-8 results and indication of any significant trends, as follows:

(1) MSK versus DRK Usage. This analysis should be completed by analyzing GT-8 data on one additional console (Console 8, GNC) and the complete six-console analysis run for one additional mission.

(2) D/TV Channel Outages. This analysis should be performed for a mission considerably longer than GT-8, in order to determine whether mission duration has any significant effect on channel availability.

(3) CIM Loading Analysis. This should be repeated for one additional mission.

Improvements in Analysis Techniques

It is recommended that various improvements be made in the analysis techniques, as follows:

(1) Contact and working relationships should be established between MITRE and operational personnel engaged in actual flight control activities; only in this way can certain facts obtained from analysis be interpreted correctly.

(2) The averaging effect introduced by use of 20-minute time intervals should be eliminated, in some cases, by working with instantaneous changes in system status and demand. This applies particularly to the Total Console Module Activity Analysis, where it would permit the calculation of console request interarrival times. This analysis

would also be improved by obtaining data for individual consoles as well as totals.

(3) The D/TV Channel Saturation analysis should be extended to give a complete distribution of channel assignment; i.e., not just in two ranges (24 to 25 channels and 26 to 28 channels) but in unit ranges from 0 to 28, plus additional "demand" ranges above 28 (channels demanded but not assigned because of saturation).

(4) Some means of automating the present tedious manual procedures for analyzing usage data is almost mandatory. It is recommended that effort begin at once on developing a computer program to perform these procedures automatically and rapidly, and to output either tabular data or final curves. This recommendation applies to all analyses reported here as well as to new analyses recommended in the following paragraphs.

New Analyses

It is recommended that two analyses not performed in this study (but based on same) be designed and carried out for GT-8 and other missions, as described below:

(1) RTCC Delays. The acquisition of data on various display outputs from the RTCC, followed by comparison with input request data, is recommended as one means of determining RTCC time delay in processing display requests (this delay is one unknown factor in estimating total system delays). This analysis should be carried out for GT-8 and several other missions.

(2) Trend Analysis. A trend analysis based on usage data from more than one mission should be developed, primarily for the purpose of establishing mission-to-mission trends and correlations. A quantitative analysis of this type need not be excessively complex, but is of exceedingly great importance in estimating system requirements for future missions.

INSTITUTION OF DIFFERENT TYPES OF STUDIES

Three types of studies, somewhat different from the Usage Analysis Studies reported here, are recommended for consideration; these are described in the following.

Display Structure and Content Study

It is recommended that consideration be given to a study of display formats, from a design point of view and for the purpose of determining if it is desirable and practical to eliminate and/or combine some of the formats. Such a study would necessarily involve operational procedures, needs, and policies, and could turn out to involve fairly extensive analysis of display content. Factors which might be considered are redundancy, character density, operator preference, and a usage factor for each format. The results of this study could, by reducing the number of computer-stored formats, decrease the number of display-retrieval actions and increase the average information content of the displays; this would both reduce the time required of the RTCC to handle display requests and decrease the demand for the (limited) number of D/TV channels available.

Study of Demand/Performance Models

The performance of the display system (or of any system involving man/machine interaction) is dependent on two factors:

(1) The way in which various system hardware and software elements operate.
(2) The demand placed upon the system, primarily by human operators.

In the present case, the first factor involves operating characteristics which are either well understood or can be easily measured; in the aggregate, these characteristics (expressed numerically) form a mathematical model of the system. Where only a portion of the total system is of interest, such a model is often relatively simple and straightforward.

The second factor, involving as it does the complex and partially-random interactions of a large number of operators, cannot be described by a deterministic model such as used for the system hardware. Here, a statistical model is more appropriate. Again, such models are often simple (e.g., in the form of distributions such as those plotted in some of the figures of SECTION IV), but may be more difficult to construct.

It is recommended that a study be performed for the purpose of constructing models of both types which can reasonably approximate the operation of the display system with regard to its display-retrieval function. The two types of model would be designed to work together, with the statistical model serving as "input" to the deterministic one; the resulting composite model could then be used (analytically or via simulation techniques) to predict system performance for a variety of operating conditions and over a range of system loads. In turn, this allows the prediction of system adequacy for future missions and enables one to make various redesign tradeoffs. A study of this type would complement the various usage analyses recommended; e.g., it might make use of certain statistics gathered from usage data and might indicate additional types of usage data which are important.

System Configuration Study

Recommended for consideration is this fairly broad study encompassing various system-level concepts and questions pertinent to the Display and Control System. The objective would be to provide NASA with the quantitative information necessary for making acquisition and design decisions for that system.

Examples of appropriate subject-areas for investigation include the following:

(1) The variation and balance, among various system elements, of the ratio of capacity to demand. As an example, if this ratio were 1.2 for a certain unit, and 1.8 for a second unit, and if these two units are always used together in response to the same demand, then the extra 60% over-capacity of the second unit can never be utilized. This ratio is closely connected with the economic factor of percent utilization of equipment.

(2) The degree of centralization of display refresh memory, i.e., the degree to which such memory capacity is available for common use (on a space-sharing basis) to the individual console operators. This factor can significantly affect both equipment costs and performance of the system.

(3) The desirability and practicality of doing at least part of the pre-mission reconfiguration (re-wiring, patching, etc) via computer software.

(4) The interactions and mutual effects, between the display system and other systems, due to changes in the design or operation of either.

(5) The degree of standardization (in hardware, system configuration, console configuration, etc.,) which best suits the needs of the MCC.

(6) The potential application and incorporation of new advances in display and control technology. This implies continuous cognizance of new techniques and devices (e.g., computer time sharing, on-line graphics, light pen input techniques, "RAND Tablet" devices, electronic character generation, electroluminescent and reflective display surfaces, the use of displayed "keyboards" and cursors, and the dialing of telephone connections via the display surface).

(7) Performance-degradation curves which show how system performance is degraded by both increases in loading and decreases (due to equipment malfunctions) in system capability. The latter would indicate the extent to which the system was "fail soft", i.e., to which gradual, instead of abrupt, performance degradation occurred.

The aggregate knowledge gained in the above study areas should serve to more precisely define the tradeoffs which can be made with respect to the Display and Control System. They should lead to quantitative procedures for predicting the consequences of various choices in system configuration, and, ultimately, in making tradeoffs between factors such as capital expenditures and costs, procurement time, obsolescence, performance, flexibility, and back-up capability.

A. S. Goldstein

A. S. Goldstein

G. B. Hawthorne, Jr.

G. B. Hawthorne, Jr.

APPENDIX A

BIBLIOGRAPHY

1. Display Formats Manual, PHO-TR 147, 4/27/64
2. XY Plotboards, SOW IV 2526-01203, 1/31/64
3. Front Surface Mirrors Acceptance Test Spec., PHO 98-03501, 2/16/65
4. Group Display Subsystem Spec., 1S 2700-00065A, 9/26/63
5. Converter Slide File D/TV Converter (Optical and Mechanical Interface Spec.), 1S 2502-00216, 4/6/64
6. Hardcopy Output Recording Equipment, Code 09205, 9/12/63
7. Countdown Transmission System Procurement Spec., 4S 0000-00220B, 7/2/64
8. Lesson Plans and Handouts (Gemini Network Training), FCDQP 7.12.00
9. PHO-MCC Index of Philco Documentation, 11/30/65
10. D/TV Converter Spec. (Plus Amendment 1), 1S 2502-00090B, 1/31/64
11. CDC1S Spec. (Plus Amend. 1), 1S 2500-00073D, 10/6/64
12. PHO Specification 1S 2101-00210 A (Plus Amend. 2), 3/4/64
13. PHO Maintenance Manual EM 226 (XY Plotboard), Vol. 1 and II, 10/15/64
14. PHO Maintenance Manual EM 233 (Projection Plotting Display Equipment), Vol. I and II, 6/1/65
15. Time Display Converters Procurement Spec., 1S 2100-00226A, 7/1/64
16. Television Camera Equipment for IMCC Spec. (Plus Amend I and 2), 1S2101-00210A, 3/4/64
17. Television Test Generator 945-Line Spec., 1S 2100-01258, 7/8/64
18. Land-Line Interface Spec., 1S 2100-01249, 6/24/64
19. Opaque Televisor Spec., 1S 2100-01255, 6/29/64
20. 945-to 525 Line TV Standards Converter Spec., 1S 2100-01259 7/8/64
21. 525 to 945 Line TV Standards Converter Spec., 1S2100-01260, 7/9/64
22. 14-Inch Precision Console Display Procurement Spec. 1S 2106-00209A, 10/4/63
23. Video Engineers Console Spec., 1S 2100-01250, 6/25/64
24. PHO Maintenance Manual CDC1S (Preliminary, Vol. I, II), SM-206
25. MCCH Console Modules, By Module Type
26. Description of Console Modules, PHO TR-120 Vol I, Book 2, Revision 14, 9/22/64
27. MSCC Television Subsystem Spec., 1S 2100-00061B
28. Television Subsystem Maintenance Manual, PHO SM-202, Vol I, 12/15/64
29. Video Switching Matrices Maintenance Manual, PHO EM-214, 1/1/65
30. Timing Subsystem Spec. (Plus Amend. 1 and 2), 1S 2400-00067D, 3/31/64
31. Console Subsystem Spec. (Plus Amend. 1, 2, 3), 1S 2200-00063
32. Module Specifications (Individual Console Modules)
33. Video Scanner Control Maintenance Manual, PHO EM-240, 9/15/64

APPENDIX A

BIBLIOGRAPHY (Cont'd)

34. Console Subsystem Maintenance Manual, PHO-SM 203, 2-15-64 Vol. I.
35. Data Retrieval and Interpretation Program, PHO-TR212.
36. Maintenance Manual, CDCIS Interface Subsystem, PHO-SM 206, Vols. I, II, III, IV.
37. MCC-Houston Operational Configuration-Gemini VIII, PHO-TR155, Vol I, 26 April 1965.
38. Group Display Subsystem Spec., 15-2700-00065A, 9/26/63.
39. Gemini VIII FCDAR, Revision B.
40. Apollo FCDAR, NS-2/AS-204, 3/11/66.
41. MSK Tabulation, 1N2500-00316D, 7/29/64.
42. MSK Tabulation, 1N2500-00320D, 7/29/64.
43. Mission Operations Support Laboratory System Specification, 5S1000-01285A, 3/9/65.
44. Gemini MCC-H Flight Control Console Handbook (Preliminary No. 2), 2/15/66
45. Console Operator Manual, PHO-OM201, 12/15/64.
46. Pneumatic Tube Subsystems/Equipment Maintenance Manual, PHO-5M106, 12/15/64.
47. MCC-H Operational Configurations, MOCR-1, TR155, Vols. 2,3,4,5.

APPENDIX B

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